Many Faces of Mobile Contactless Ticketing

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***Abstract*—Smart cities must offer innovative mobile services in the areas of transport and culture. In this context, the ticketing services, which are key elements in the domains of transport and culture, have to be provided. In this respect, the impact of technological developments, including those related to NFC (Near Field Communication), which is a short range wireless technology, lead to the deployment of mobile contactless solutions. We highlight, in the paper, seven models to manage all or part of mobile contactless ticketing systems within smart cities. This study is based on the research conducted in the contactless ticketing area and on the return of experience gained within a European project. The models, which give a realistic picture of the various faces of such systems, are: the operator-centric model, the manufacturer-centric model, the identification-based model, the peer-to-peer model, the smart card-based model, the leeched smart card-based model, and the inverse reader model. We detail the characteristics of each model and present use cases. Furthermore, we present tracks indicating that these models may coexist within smart cities and we derive some perspectives on the evolution of these ticketing services by explaining that two models could be dominant.**

Keywords-mobile services; mobile ticketing; contactless; NFC

I. INTRODUCTION

The concept of *smart cities* refers to cities that have consented to invest in information and communication technologies so that innovative services can be deployed to facilitate the operations of daily life for the citizens [1]. Within smart cities, information and communication technologies are used to improve the legacy systems in the areas of transportation, education, commerce, culture or administration while preserving their successful integration into the urban environment of the end-users.

The mobile phone has become an ubiquitous tool to interact with smart cities services, because of its penetration within the population. For example a citizen could use the same mobile equipment to pay for transit ticket (for a bus) and view the real-time traffic of buses. Thus, smart cities, through mobile services based on new technologies, must provide their citizens with services in the areas of transportation, education, commerce, and culture. In the domains of transport and culture, a key parameter is the ticketing management system. Indeed, access to means of transport or to events is determined by the fact that the users hold valid tickets. The ticketing services are therefore essential and mobile-based solutions must be developed.

One of the promising technologies for the mobile services is the contactless technology. The vision is that smart cities can exploit this technology in the domains of transportation and culture to offer ticketing services. The trick is that the end-user only touches dedicated equipment with the mobile phone, accepts the transaction and gets the access to the proposed service. This is, in our terminology, an example of mobile contactless city services. Mobile contactless services in smart cities are and will be based on Near Field Communication (NFC) [2], which is a wireless technology that takes its roots in Radio Frequency Identification (RFID). It has a range of about 10 centimeters. NFC offers three modes of operation: reader/writer, peer-to-peer and card emulation. The reader/writer mode makes it possible for NFC devices to interact with passive NFC tags. The peer-to-peer (P2P) mode supports direct communication between NFC devices, and the card emulation mode allows a NFC device to act as if it were a smart card. In the latter case, in order to store sensitive data, NFC devices offer support for an embedded smart card chip that is called a secure element.

In the framework of the Smart Urban Spaces (SUS) European project [3], we explored the possibilities offered by the NFC technology in the field of mobile ticketing for city services. The question that arises is: what are the different models of efficient NFC-enabled mobile ticketing systems that can be deployed in smart cities. The aim of our work is thus to present and analyze systems dedicated to mobile contactless ticketing that we consider relevant in the context of smart cities. In the remaining of the paper, we first propose an overview of some research projects regarding the concept of contactless ticketing. Then, in section III we give a description of the key elements in the environment of mobile contactless ticketing while section IV presents the different models, used to provide the ticketing services, which we choose to highlight. Finally, in section V we delineate some perspectives to understand the possible evolution of mobile contactless ticketing services before concluding.

II. STATE-OF-ART IN CONTACTLESS TICKETING

Ticketing systems aim at proposing solutions with electronic tickets (e-tickets) and paperless operations. The use of NFC is one of the most appropriate options to provide such systems. We present here some projects, in the domains of transportation and events management, which are representative of what is done for contactless ticketing.

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A. *The domain of transportation*

Public transport operators are very keen on deploying contactless e-ticketing systems. For example, the Oyster card in London [4] and the Yikatong in Beijing [5] are transportation cards based on the MIFARE technology [6]. As another example, in Hong Kong, the Octopus Card [7] is a transport operator card based on the FeliCa technology [8]. MIFARE and FeliCa are contactless cards technologies. In these systems, the loading of tickets is done either online or via dedicated machines. Then, the users get access to the stations just by touching specific readers with their cards.

Another interesting project is the Virtual Ticketing application. Indeed, by taking advantage of the NFC technology, Ghiron et al. [9] proposed a ticketing application for transport in Rome. In the developed prototype, the virtual tickets are stored in a mobile equipment which is used to perform the different operations. The French transportation company Ligne d'Azur in collaboration with the Cityzi project in Nice offers a similar service for buses [10]. With a dedicated mobile application loaded on a mobile phone, the users are able to buy tickets and validate them by using NFC.

More generally, Widman et al. discuss in [11] the integration of NFC ticketing systems into existing transport infrastructure. Such systems can be successfully integrated by considering, among other things, the following points: the distribution of the application, the distribution of the tickets, the display of the tickets (to inform the user), and the procedures of inspection (to check the validity of presented tickets). The relevance of the scenario is demonstrated by applying the concept to the VDV (Association of German Transport Companies) Core Application.

B. *The domain of events management*

The events e-ticketing initiatives that rely on the use of contactless technologies are very limited. However, these initiatives demonstrate the added value of NFC in ticketing services. An interesting project is the Tapango system [12], implemented by the Artesis' research lab. It is an electronic voucher system based on e-Wallets with the use of NFC smart cards or NFC-enabled mobile phones. The objective of the system is to reduce the use of paper tickets. With Tapango, the users first buy tickets via a web interface. Then, at the event location they synchronize their e-Wallet (by interacting, through their cards or their mobile phones, with a machine connected to the Internet) to "physically" obtain the tickets and finally they can present the acquired tickets to get access to the show.

Another interesting example is the pilot [13] related to events ticketing in the theatre of the city of Oulu (Finland) that was deployed in the framework of the SmartTouch project [14]. At the theatre site, the users interacted with specific equipment in a point of sale to receive the purchased tickets on their NFC-enabled phones. The inspection of the presented tickets was achieved with another NFC-enabled mobile phone by using the NFC peer-to-peer mode.

III. Mobile Contactless Ticketing Environment

Contactless card environment was brought to mass market in 1997 when Hong Kong introduced their Octopus card system. The same contactless smart card standard (ISO/IEC 14443) has been carried to the mobile contactless world so that NFC devices can interact and communicate with compatible contactless smart cards and readers. This backward compatibility gives the already existing ecosystem a domain to tap into.

The card emulation mode of NFC, which offers a support for a secure element, is the one that has been designed to be used with ticketing. There are several options for the secure element. The two most prominent are the embedded secure element option where the secure element is controlled by a manufacturer and the UICC (Universal Integrated Circuit Card) option where the secure element is controlled by a mobile network operator. The strict control of the secure element is essential to ensure the security of the chip, but it prevents an efficient utilization of the chip by 3rd parties. In section IV we present different ticketing models, some of them require a restricted platform and thus make use of the secure element.

A Gartner predicts that in 2015 50% of smart phones would be equipped with NFC [15]. This means that mass market ticketing schemes can start adopting mobile contactless ticketing but, at the same time, it cannot abandon the current plastic card infrastructure. SMS-based and web-based ticketing solutions are already so cost-efficient, that mobile contactless ticketing needs to find its edge somewhere else. User experience is usually considered to be the selling point for contactless services and the ticketing domain should be no different.

IV. Models for Mobile contactless ticketing

Due the complexity of mobile contactless ticketing environment, there are many possibilities on how to develop solutions. In this section, we present seven different ways that seem most relevant, in the context of smart cities, to manage mobile contactless ticketing systems.

A. *Operator-centric model*

GSMA is the global association of network operators that has created a model to build mobile contactless services which ticketing is one of. The GSMA's operator-centric model is based on the use of an UICC as a secure element [16][17]. The use of UICC, which is inserted in a mobile device, gives operators the control of the mobile contactless ecosystem. Because there are several operators and service providers would like their services to be available for all possible customers, the operator-centric model requires the use of an entity called the Trusted Service Manager (TSM). TSM creates an interface for service providers so that they can seamlessly deploy the ticketing applications via this interface, which hides the diversity of operators. TSM can also be the actor that is really in contact with the customer UICC by using the security keys provided by the operators.

As the services are in the UICC, they are transferred along when the consumer changes his or her mobile device to another. An acknowledged problem with this model is the still undefined process of secure element roaming when the user travels in countries with another operator’s network. In others words, the problem is to know how the home operator would update and communicate with the secure element in a roaming context. The architecture of the model is presented in the Fig. 1.

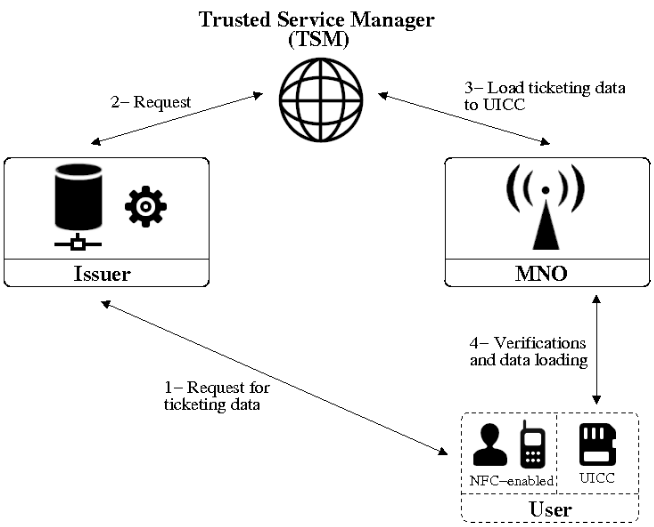

Figure 1. Architecture of the operator-centric model

The operator-centric model is in operation for example in France which is a pioneer of NFC ecosystems with the Cityzi smart city initiative. The operator-centric model is the closest to the industry standard at this time. The major players are behind it and NFC Forum, as a standardization body in the NFC ecosystem, has promoted it as well. Transport For London deployed a mobile contactless ticketing pilot in 2012 [18]. They considered it to be a failed one because the read-speed of ticket when using the UICC as a secure element was too slow for them. Current Oyster card operates at speed of 300ms but the operator-centric model was not able to achieve a validation speed of 500ms that has been considered as a limit for smooth ticketing.

B. *Manufacturer-centric model*

Similar to the operator-centric model is the manufacturer-centric model in which an embedded secure element (in the mobile equipment) is used the storage of sensitive information [16]. The embedded secure element is controlled by the manufacturer. The architecture of the model is presented in the Fig. 2.

For the consumer they seem to be quite similar and most of the difference appears when the consumer changes his or her mobile device (to use the mobile phone of another manufacturer) and the services cannot be transferred in the process. As the model is operator agnostic, the user may change his or her operator easier. The manufacturer-centric model is championed by Google currently. Nokia was also formerly involved in the promotion of the model, but it changed to the operator-centric model.

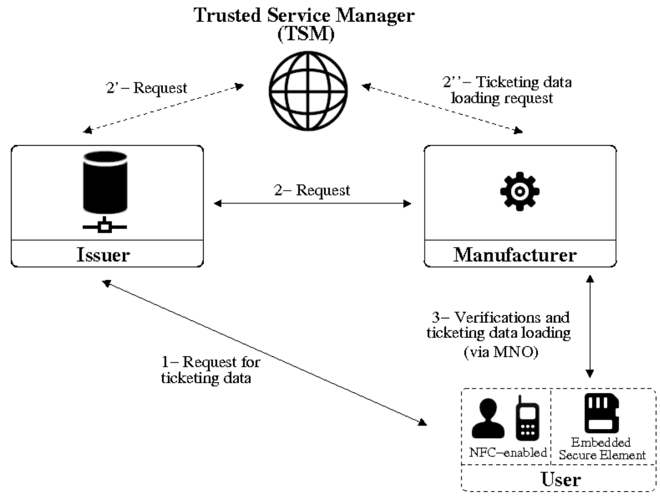

Figure 2. Architecture of the manufacturer-centric model

In practical way, the manufacturer-centric model is used in the Google Wallet –application where the sensitive data is stored in the embedded secure element of Google compliant mobile phones.

C. *Identification-based ticketing*

Identification-based ticketing tries to circumvent the need to store dynamic information in the device of the user. In this context the ticket can be seen as dynamic information which changes for every separate ticketing case. The assumption is that there is a static identifier stored in the secure element of the user’s mobile device. The same static identifier is also stored in the ticket issuer’s backend system where all the dynamic information is processed.

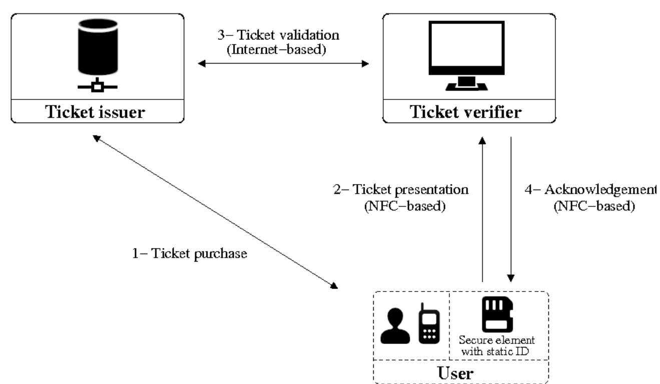

Figure 3. Architecture of the identification-based model

This ticketing system requires a secure element to be available in the user’s mobile device so that the static identifier can be stored. This secure element may be a UICC or another secure element that is embedded in the device. The ticketing architecture is described in the Fig. 3. At the gate, the right to enter is verified by reading the identifier from the secure element of the user's mobile device and then sending it to the ticket issuer's system. It returns the authorization (or not) to enter. When the user buys a ticket for a specific event from a ticket issuer, the ticket is stored in the ticket issuer's back end system and it is connected to the static identifier stored in the user's mobile device secure element. The identifier-based ticketing model is used in Oulu (Finland) where the city card chip ID is the relevant key to manage the access rights. Thus far, only smart cards are commonly used but the mobile phone use has already been tested [19].

D. Peer-to-peer ticketing

Peer-to-peer ticketing does not offer the same level of security than the one that can be achieved, for example, with the operator-centric model. However, it excels in creating a light-weight open ticketing system without the need of big companies that control the market with secure elements [20].

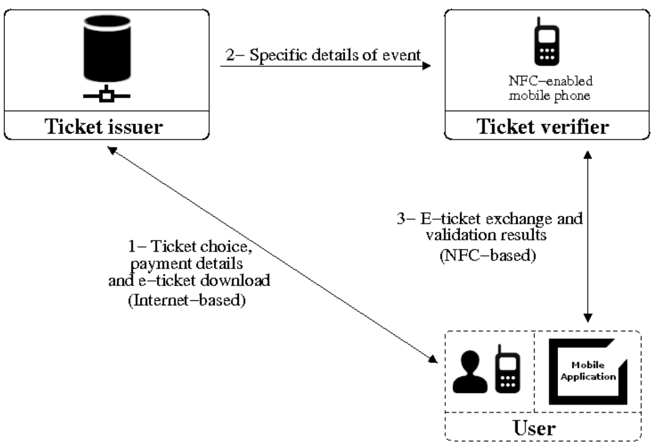

Figure 4. Architecture of the peer-to-peer model

In the peer-to-peer model, the ticket is stored in the user's phone memory when it is bought over the air. During the validation phase, the NFC peer-to-peer functionality is used to transfer the ticket from the user's mobile device to the validator's mobile device where the ticket's validity is checked as described in the Fig. 4. The validator device must keep track of the presented tickets and must contain the mechanisms to check the validity of the tickets. This procedure is made possible by the fact that the validator application is provided, beforehand, with the necessary information regarding the validation process.

This ticketing model was tested and piloted in Bordeaux during social events of computer science conferences and projects meetings (among the pilots deployed during the SUS project).

E. Smart card –based mobile ticketing

Smart card –based mobile ticketing is the model which is the closest to the legacy model of ticketing. The basic infrastructure, which is composed of a smart card and a reader, is changed into an infrastructure with a smart card and a mobile device. The description of the architecture, where the ticket issuance is not considered, is presented in the Fig. 5. The functionalities are the same and the great benefit is that the old legacy (smart card-based) systems can work with new mobile devices equipped with the reader technology. Mobile devices that require a human being to operate them are not economically feasible in comparison to the automatic readers used in public transportation. The advantage comes from having a mobile platform that can be deployed at small costs anywhere. This light-weight approach is suitable, for example, in events where there is a temporary need to have personnel on the field.

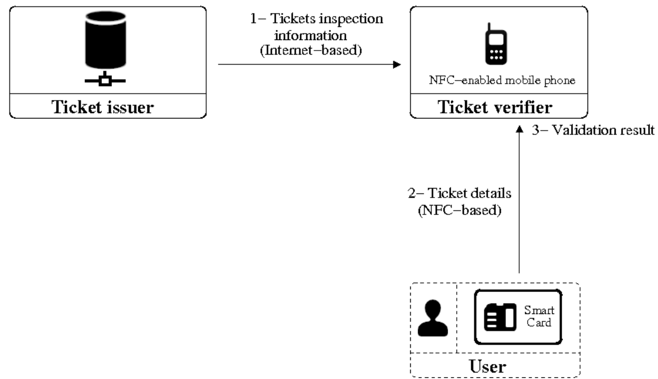

Figure 5. Architecture of the smart card-based model

This model has been deployed in Turku, Finland, where inspectors have used mobile phones when inspecting tickets in busses and other public transportation vehicles (among the pilots deployed during the SUS project).

F. Leeched smart card –based ticketing

The leeched smart card –based ticketing model is founded on the principle that the general populace has already a variety of plastic cards which can be transport cards, payment cards or loyalty cards. This medium can be used as an identifier platform that is linked to a ticket that is stored in the back end system.

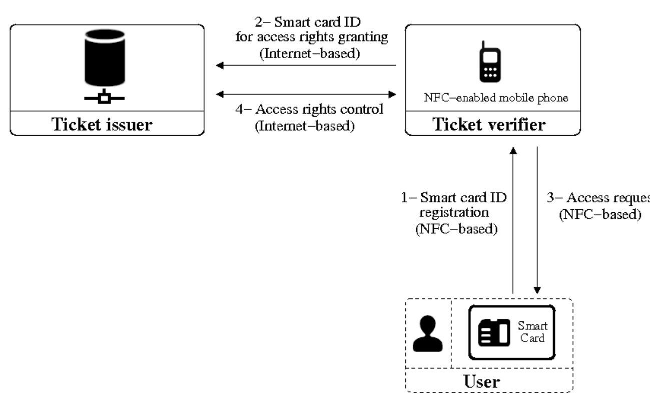

Figure 6. Architecture of the leeched smart card model

An example of this ticketing model was piloted during the Open Europeans 2011 sailing event where Helsinki

Region Transport –card was used as a ticketing medium [21]. There were two technical options: to use the card ID or the ID of an application stored in the card. The latter was chosen as Helsinki Region Transport Authority wanted to test its feasibility. In addition, the users used the public transportation with the same card.

The validation of the ticket is done by a mobile phone. A validating person reads the identifier from the smart card with his or her mobile device. The identifier is sent to the back end system where the validity of the ticket is checked. The information is then returned back to the mobile device where the screen shows if the ticket was valid or not. All this process is presented in the Fig. 6.

G. Inverse Reader ticketing

Saminger et al. [22] are suggesting that reversing the architecture of ticketing could be a possible way to go around the secure element problem. As the mobile device environment is closed regarding the secure element architecture, the inverse reader ticketing achieves the validation process through a NFC mode mismatch.

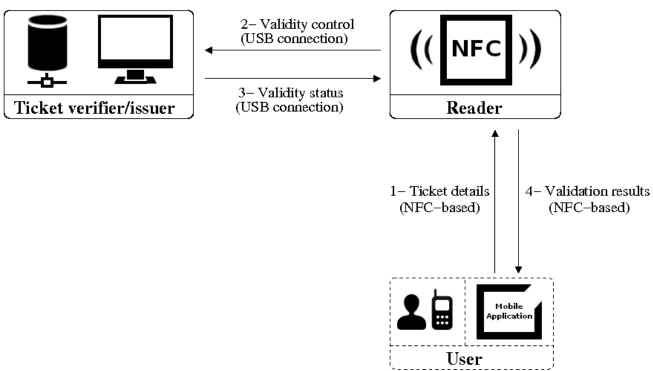

Figure 7. Architecture of the inverse reader model

The system works in a way that the mobile device is in reader/writer mode and the reader, which is linked to a server, operates in card emulation mode (Fig. 7). The ticket itself is stored in the mobile device. When the ticket is presented, the server checks the validity and returns the information to the mobile device. The advantage of this solution lied in the good level of interoperability, in the coverage of interoperable reader/writer mode, and in the use of a light-weight protocol stack of card emulation.

H. Summary

Table I and Table II integrate the 7 models presented for the mobile contactless ticketing options. To highlight their differences and their specificities, the proposed tables provide an overview of the models regarding different classification categories.

TABLE I. DIFFERENT MOBILE CONTACTLESS TICKETING MODELS

Ticketing model	*Customer device*	*Reader device*	*Place of ticket*
Operator-centric model	Mobile phone	Ticket reader	UICC
Manufacturer-centric model	Mobile phone	Ticket reader	Embedded SE
Peer-to-Peer ticketing	Mobile phone	Mobile phone	Phone memory
ID-based ticketing	Mobile phone	Mobile phone	Back end server
Leeched smart card –ticketing	Smart card	Mobile phone	Back end system
Smart card-ticketing	Smart card	Mobile phone	Smart card
Inverse reader ticketing	Mobile phone	Ticket reader	Phone memory

TABLE II. DETAILS OF DIFFERENT MOBILE CONTACTLESS TICKETING MODELS

Ticketing model	*Need of network*	*Contactless protocol*	*Suggested usage*
Operator-centric model	No	Card emulation	All ticketing (too slow for transport?)
Manufacturer-centric model	No	Card emulation	All ticketing
Peer-to-Peer ticketing	No	Peer-to-Peer	Small event ticketing
ID-based ticketing	Yes	Card emulation	Non-transport ticketing
Leeched smart card –ticketing	Yes	Tag reading	Event ticketing
Smart card-ticketing	No	Tag reading	All ticketing
Inverse reader ticketing	Yes	Tag reading / card emulation	Non-transport ticketing

In our opinion, the relevant categories are: the customer device, the reader device, the place of the ticket, the need of network, the contactless protocol, and the suggested usage.

V. WHAT'S IN THE FUTURE?

The diversity of situations an end-user may encounter and the compliance with its preferences makes it necessary to provide mobile contactless ticketing systems of different types. It is also essential for the proposed (innovative) solutions to be interoperable with legacy systems. These elements allow us to assume that the presented ticketing systems can coexist. For example, an end-user, with the same mobile phone, could use a peer-to-peer system to attend a small exhibition while he would use a secure element -based system to store a ticket to a concert.

However, we also assume that MNOs and manufacturers of mobile phones, because of their economic power, can put forward (what they already do) the operator-based and the manufacturer-based models. They have many customers and they can, somehow, impose their rules on some practices. It is currently unclear which of the two models could eventually be preeminent. We can still note that in some areas, notably the transportation domain, infrastructures are difficult to change (due to the costs of investments and the practical problems of passenger flow) which does not make obvious the possibility of imposing rules on some practices.

In our opinion, the challenge lies in being able to present a clear and coherent picture of the environment so that the end-users can easily understand what the most suitable service is in each possible situation. In the case the different models coexist, it will probably be necessary to provide a service aggregator adapted to the context (automatic selection of the proper application, interoperability between the applications, etc.) in order to foster the user friendliness and keep the end-user at the center of the process.

VI. Conclusion

One characteristic of smart cities is the possibility to grant a person a right to do something. These rights are usually controlled by tickets which represent proofs of entitlement. For example, a transport ticket gives its holder a right to travel to a given destination. Mobile contactless ticketing aims at making the ticketing systems smarter and easier to use.

There are several models available to manage mobile contactless ticketing. We have presented seven different models that are already in use or are in proof-of-concept phase. The presented models are: the operator-centric model, the manufacturer-centric model, the peer-to-peer ticketing, the ID-based ticketing, the leeched smart card model, the smart card ticketing model, and the inverse reader ticketing model. The first two models are the industry pushed models and they should become more prominent. The other five models are suitable for smaller and more focused use cases and will certainly coexist in the smart cities environment.

The role of the secure element will continue to pose problems in the future if the relevant stakeholders do not cooperate in building a robust and clear ecosystem for ticketing. This situation opens a room for the existence of non-secure element ticketing solutions which should excel regarding friendliness aspects to be profitable.

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