

# DOVIR: Virtualizing Food Donation Distribution through Mobile Application and Cloud-Based Supply Chain Management

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**Abstract**—Food insecurity, the lack of access to safe, nutritious and adequate food, has remained a persistent and major problem in our society, particularly in low-income communities. It leads to many serious consequences, including hunger, malnutrition in children, poor health conditions in adults and early mortality. One direction to address food insecurity is to facilitate streamlined food donation from communities with surplus food. In this paper, we present an approach, DOVIR, to address this crucial problem. DOVIR includes mobile smartphone application together with cloud-based services to create a virtualized infrastructure for enabling precise, in-time food donation. We discuss the architecture of DOVIR, and several design considerations to ensure its practical viability.

**Index Terms**—Food security, Smart donation, Smartphone application

## I. INTRODUCTION

The problem of food insecurity refers to lack of access to safe, nutritious and adequate food [6], [8]. In spite of significant growth in food production over the last decade, food security remains a global, societal problem. In 2018, an estimated 11.1% of US households were food insecure, with the number rising to 13.9% for households with children [9]. The global picture is much grimmer, with nearly a billion food insecure people across the globe. Food insecurity is associated with lower diet quality, negative health outcomes, and increased healthcare costs. A critical contributor to food insecurity is food waste. In the state of Florida, about 2.8 million people are subjected to hunger, including nearly 800,000 children and 550,000 seniors; on the other hand, studies have shown that enough nutritious food is grown to feed the entire population, but both pre-consumer and post-consumer food loss and waste leads to almost 40% produced not eaten [5].

An obvious approach to significantly ameliorate food waste is to donate surplus foods. While food banks and food pantries address immediate food access needs by providing food donated by individuals, groups, and retailers, the current food donation system is inefficient and complex, involving too many hand-offs. The inefficiency becomes more acute in times of natural disasters: in April 2020 during the COVID-19 pandemic, the breakdown in supply chain caused retailers and farmers to destroy vegetables and kill livestock while many food banks and pantries ran out of inventory in various parts of the United States [1]. Furthermore, there remains a disconnect between the dietary needs of a food insecure community and

the food items donated: during hurricane IRMA, there was surplus in donated canned tomatoes while other essential food items remained in short supply. Such “blind donation” may cause various problems, including food waste, insufficient food from certain food groups, and extra food storage and transportation cost.

In this paper, we present a system, DOVIR, for streamlining food donation through an electronic virtualization infrastructure. The focus of DOVIR is to connect prospective food donors directly to food insecure communities through a matchmaking process; the approach is inspired by ride-share applications but accounts for the quirks and complexities of the food distribution supply chain. DOVIR includes a smartphone application at the front end, supported by a cloud-based infrastructure management back end, with extendible interfaces for seamlessly connecting smart IoT tracking devices to automatically identify food consumption patterns as well as data analytics engines to predict donation needs. The approach enables direct, informed donation to communities with targeted needs for specific products within a specific timeline. Following are some key features:

- **In-time Donation:** A food item may be needed within a specific time interval. Our approach enables the donor community to account for such time limits. This is particularly relevant for donation of perishable items or items nearing expiration of “best by” dates. Retail stores often donate items that are nearing expiration dates. By connecting them to food-insecure consumer communities that can utilize the food in time, our approach will drastically reduce food waste.
- **Precision Donation:** A specific food item might be needed by a specific consumer, and the donor community would be more inclined to donate if it is informed of that need. For example, a donor might be more inspired to donate an item that would be of immediate necessity to a hungry kid in a food-insecure community. Our approach enables donors to target specific needs.
- **Donor Community Engagement:** In current donation process, the donor has no *a posteriori* knowledge about what happens with the donated item. Our approach enables integration and engagement of the donor in the donation process (including precision and in-time donation

as discussed above). Furthermore, it enables the donors to track the flow of donated items, providing the satisfaction of knowing when the items reach the recipient.

DOVIR has been designed with the goal for expedited deployment, not just a research prototype. The authors are currently interacting with several food banks and food pantries in several counties in United States to determine effective pathways for deployment of this solution. We are also exploring deployment opportunities in other countries, most notably in Bangalore, India. In addition to providing a step (admittedly a baby step) in the direction of addressing a quintessential social problem (*i.e.*, hunger), our work provides a compelling instance of the crucial role that can be played by systems developed through careful composition of IoT devices, mobile applications, connectivity, and cloud-based analytics to provide pervasive solutions to global challenges.

## II. BACKGROUND AND RELATED WORK

Food donation involves a complex supply chain connecting donors and consumers. The donor typically donates through individual food drives, donation channels in grocery stores and superstores, or through specific facilities in their local communities including food pantries or soup kitchens. A key component managing and coordinating donations is the *food bank*. The specific responsibilities of food bank varies from country to country. Some food banks give out food directly to the hungry, *e.g.*, in Europe. In North America they collect product from the food industry and food drives, and distribute it to various “more local” agencies including food pantries, soup kitchens, etc. A food bank in the United States typically distributes millions of pounds of grocery product every year. A food pantry is generally a self-governing entity that distributes bags or boxes of food directly to those in need who reside in a specified area. A soup kitchen, meal center, or food kitchen is a place where food is offered to the hungry usually for free or sometimes at a below-market price. They are frequently located in lower-income neighborhoods and often staffed by volunteer organizations *e.g.*, church or community groups. Obviously, each player in the donation supply chain employs significant software services for managing inventory, distribution load, etc.

There have been several recent initiatives to develop platforms to enable food donation. One such initiative in the United States is *Feeding America* [4], which provides a platform for donating to food banks. Related efforts include *Why Hunger* [10], which additionally focuses on addressing the socio-economic causes of hunger by advocating the right to food, amplifying community voices and scaling agro-ecology. There are also many initiatives outside the United States that facilitate food distribution and donation as part of a significant social program. *Action Against Hunger* [7] in Africa aims to provide food to the vulnerable sections of society, screen and treat children for undernutrition, and train and build the capacity of small scale farmers to increase production and safely store and market their crops. Zomato Feeding India aims at providing a platform to donate food, and also for

NGOs, private organizations or educational institutes to look for food. *To our knowledge, none of the existing initiatives currently within the United States or outside enables close involvement and engagement of donor community through the food donation process beyond the initial donation, or provides facilities for precision donation or prediction of donation needs.* Indeed, our work on DOVIR was inspired directly by the needs communicated by food banks and food pantries both inside and outside the United States to enable such applications.

With smartphones progressively increasing their capability, smartphone applications are being increasingly used in critical domains for heavy societal impact. For instance, similar apps have been built in smart agriculture for continuous monitoring of soil parameters and weather forecast [2], [3].

## III. DOVIR DESIGN

The goal of DOVIR is to seamlessly connect potential donors with food-insecure communities and individuals. Fig. 1 illustrates the high-level functionality of DOVIR. The idea is inspired by matchmaking architectures in ride-sharing applications. In particular, DOVIR enables food-insecure households and communities to convey donation needs, potential donors (both individual and household) to identify appropriate donees, and an infrastructure for managing the supply chain of the donation distribution and delivery in a way that is transparent to both donor and donee entities. The frontend of DOVIR is a smartphone application that manages interaction with the different stakeholder endpoints, *e.g.*, specification of donation needs from a donee, searching for appropriate donee by a potential donor, and tracking notification during the passage of the donation through the supply chain. The backend is a cloud-based infrastructure for inventory and supply-chain management. Fig. 2 shows the different software frameworks involved in the implementation of DOVIR.

### A. Frontend Functionality

The mobile application for DOVIR frontend is currently realized for Android platform. The implementation uses Java and XML. The frontend provides interfaces for (1) a user to sign up as a donor or donee, (2) donees to specify their donation needs, (3) donors to look up donees by community, donation needs, or simply text search,<sup>1</sup> (3) donors to use a virtual cart for donation, and (4) both donors and consumers to get notification (based on personalized settings) to enable tracking of the donation process. Fig. 3 shows two screenshots from the app, one for the donor and another for the consumer. Note that the functionality automatically ensures precision donation (*e.g.*, the donor can specify the donee they need to donate to), and timely donation (*e.g.*, for items the donee needs within a certain time limit they can specify that time).

<sup>1</sup>The text search facility is important since a donor might be motivated by specific scenarios. For instance, a donor may feel motivated to donate if they are aware that the donation would go to a hungry infant. DOVIR supports this scenario by enabling the donee to write personalized messages as part of their profile and donors to perform a free-form text search which will include these messages.

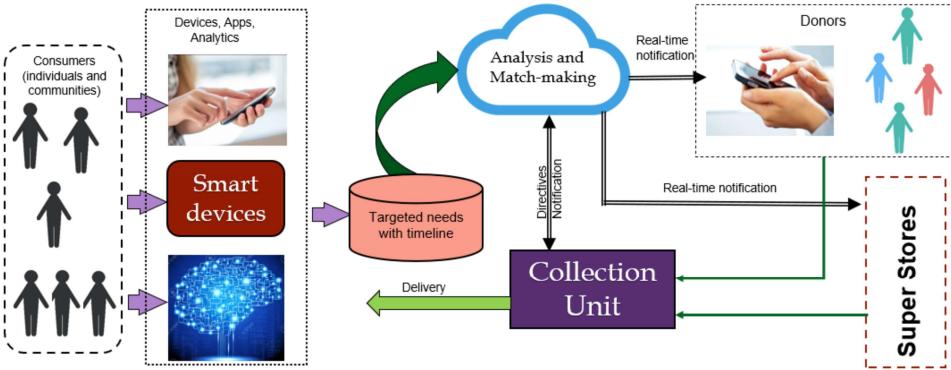


Fig. 1. Overall Functionality of the DoVIR Infrastructure

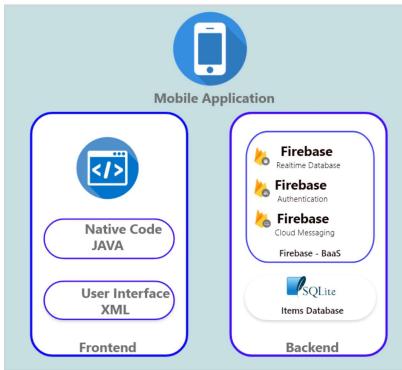


Fig. 2. Software Components involved in DoVIR Frontend and Backend

In addition to the donor and the donee, the app also supports a *delivery agent*, *i.e.*, a third party responsible for picking up the donation, and updating the tracking information (which is used to provide notification to donor and donee entities).

#### B. Backend Functionality

The backend of DoVIR is a cloud-based infrastructure implemented in Firebase. It manages (1) user authentication for both donor and donee, (2) customer notification through cloud-based messaging, and (3) an extensive (SQLite) database of food items that is used by the donor (resp., donee) users to stipulate their donation (resp., requirement).<sup>2</sup> Obviously, the implementation of DoVIR entails significant and subtle interaction of backend components with frontend to realize the overall system functionality. Fig. 4 provides a high level overview of the backend components involved and their interaction with the frontend application during donation management. Note that the management may entail several concurrent, subtle interplay of cloud services and database query.

<sup>2</sup>One might imagine that it is more flexible for donor and donee users to stipulate items as free-form texts. Indeed the app supports such stipulation. However, free-form text is vulnerable to typos, *e.g.*, if a donee mistakenly specifies “tomtoes” rather than “tomatoes” the requirement will not be discovered in a keyword search. Instead, we recommend the use of a drop down menu based on the list of items in the database. The database can be extended by additional items specified by the user. The use of a database also facilitates data analytics and predict donation needs.

#### C. Integration of Analytics and Smart Devices

A powerful aspect of DoVIR is the ability to integrate machine learning tools to predict donation needs for food items at different times of the year and at different geographical locations, based on the data collected through the app as well as historical data reported from food banks and food pantries. For instance, in coastal counties in Florida, the donation needs for canned food increase during hurricane season but subside afterwards. To enable such prediction, DoVIR frontend includes APIs to query the historical donation data, including donation frequencies and pattern of specific donors, needs of different donee communities and individuals at different times of the year, etc. This data can be linked with food pantry data, *e.g.*, in Florida we are working with food banks and food pantries as well as agencies coordinating food bank/pantry operations. Trend data obtained from the database of historical consumption and donation pattern can be used to “nudge” donors for specific contribution at specific times, *e.g.*, in Florida, a donor who habitually contributes canned food can be reminded to a specific food pantry as the hurricane season approaches, if the pantry is estimated to have a lower than adequate inventory. Correspondingly, prediction based on consumption pattern for a donee family can be used to remind them to request donation at predicted times.

A second critical feature of DoVIR is the ability to integrate diverse smart electronic sensors to facilitate integration of electronic sensory devices to identify and track consumption of donated items. This can be done through the use of a smart refrigerator with camera-based sensors for scanning food inventory, or a QR-code scanner to be updated during consumption. The tracking of consumed items can be used to send reminders to the donee to request donation as the inventory of food reduces (including specific items to request depending on usage pattern). It also facilitates robustness of the approach against abuse and exploitation (see Section III).

#### IV. VIABILITY ISSUES

One of the key targets of DoVIR is to be ready for immediate deployment in communities, not just a research prototype. Currently, it has not been deployed but the authors

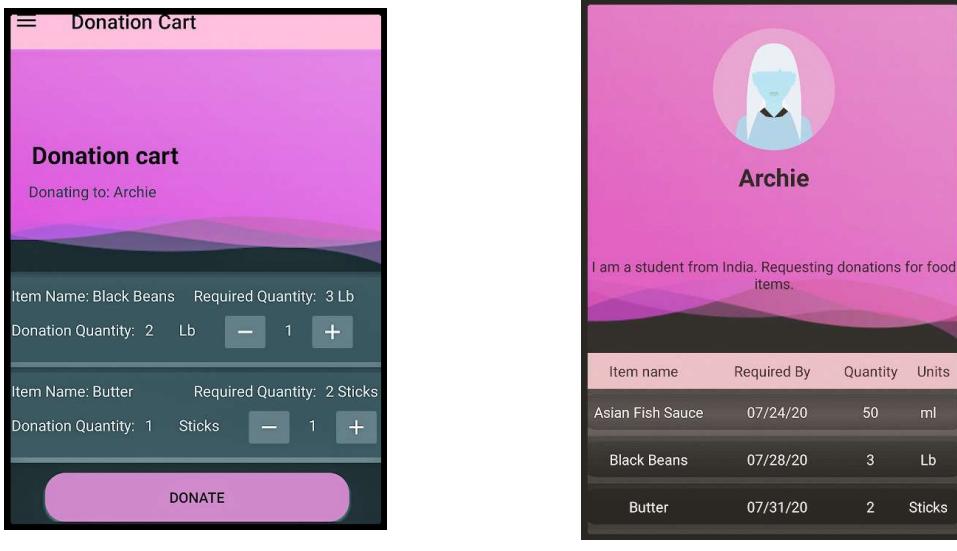


Fig. 3. Some Screenshots from DOVIR Smartphone App. (a) Donor Cart. (b) Public Profile of the Donee.

are already discussing deployment paths for the system in several communities both within the United States and other countries. Furthermore, the target users of the DOVIR frontend are not necessarily software-savvy. Making a deployment-ready system with such target requires attention to a spectrum of factors in addition to the core functionality. Some of the implementation issues considered in Section III have been led by such practical viability concerns, *e.g.*, the use of a database of food items rather than free-form text. In this section, we discuss some of the viability concerns that significantly impact the overall DOVIR design. We speculate that similar considerations might be relevant for related researches that attempt to address an aspect of a societal problem through combination of smartphone app, connectivity, and cloud-based analytics.

#### A. Robustness Against Abuse

Since the DOVIR methodology streamlines the connection between recipient and donor communities through online matchmaking, it also becomes feasible for a recipient individual to request donation of food in excess of need, possibly using the donated excess for unsavory purposes. For the system to operate smoothly, it must be robust against such abuse. One straightforward way this can happen is that the same (physical) individual creates multiple donee profiles. DOVIR provides mitigation to this abuse by requiring a two-factor authentication involving smartphone (in addition to email address);<sup>3</sup> furthermore, multiple phones registered for different donees to the same address can be flagged for manual follow-up by the donation management.

<sup>3</sup>Authentication based on more accurate identifying information such as Social Security Numbers is obviously not viable. The choice made in DOVIR marks a trade-off between accuracy and viability.

A more subtle and nuanced abuse happens if a donee (as a single profile) simply requests items in excess of requirement. DOVIR provides two pathways to address this abuse: (1) smart sensors and devices to track consumption, and (2) machine learning algorithms to predict needs. Canned and packaged food donated to an individual can be tracked through attaching simple, inexpensive sensors that can analyze the inventory of available donated food in an individual's home, in addition to the use of smart refrigerators;<sup>4</sup> the idea is for any individual subscribed to the streamlined donation matchmaking service to agree to the use of such sensors in the stocking areas in their home. Results from these sensors can be integrated with the request processing to analyze viability of the request. This "physical" tracking is complemented with machine learning paradigm that can predict viability of a request based on consumption pattern. In particular, collaborative filtering identifies the need of an individual based on historical need pattern of "similar" individuals; seeded with initial data on consumption patterns based on inventory sensors, these prediction algorithms provide a robust pathway to detect anomalies in requests, in addition to automatically predicting targeted future needs.

#### B. Absence of Individualized Smartphones

While smartphones are getting increasingly affordable, a large segment of food-insecure population still does not have access to them, particularly in the third world. DOVIR accounts for this by providing a *community profile*, that enables a single representative with smartphone (*e.g.*, the chief in a village) to represent an entire community through one profile. Each participating family still must be accounted for and

<sup>4</sup>While smart refrigerators provide a flexible infrastructure, they are expensive and may not be currently viable to donees in food insecure communities.

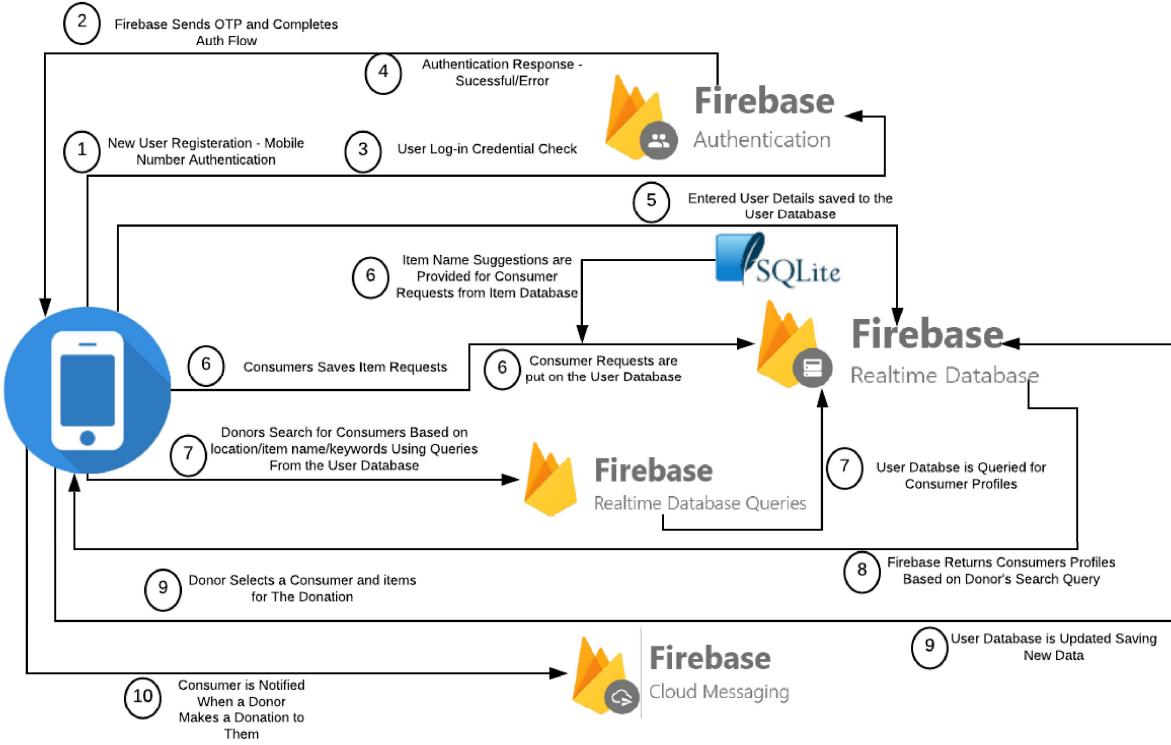


Fig. 4. Backend Components of DOVIR and their interaction with the frontend Application

explicitly delineated in the profile, and donee requirements are specified for individual families to enable precision donation and analytics. To prevent abuse as discussed above, community profiles are subjected to manual follow-up.

#### C. Privacy Issues

Obviously, DOVIR handles some personalized, private information of individuals, including phone number location, consumption pattern, family size, and even the fact that they are food insecure. Furthermore, analytics performed on individuals can identify other behavioral characteristics. DOVIR addresses privacy by keeping the personally identified details (*e.g.*, name, address, phone number) separate from their public profile; only details explicitly provided by a user as public is enabled in search. Furthermore, any analytic result must only be presented in aggregation, with the targeted user only offered the resultant notification or reminder.

#### V. CONCLUSION AND FUTURE WORK

We have presented an infrastructure, DOVIR, for enabling precision food donation through a virtualization infrastructure realized through smartphone application and cloud-based services. DOVIR enables integration of analytics and smart sensors to automate prediction of donation needs. To our knowledge, this represents the first food donation system that comprehensively virtualizes the entire supply chain and enables active and continuous engagement of the donor throughout the donation process.

DOVIR is a step towards streamlining donation, a key waypoint in addressing hunger. Future work with DOVIR will entail integration of diverse analytics and experimentation on their efficacy on real-life donation data. We are also planning to extend DOVIR to facilitate access to *healthy* diet based on individualized consumption pattern and dietary needs.

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