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Estimating surplus food supply for food rescue and delivery operations

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ABSTRACT

Hunger remains a largely hidden social problem in many developed nations. The not-for-profit food rescue organizations, aid in alleviating hunger, by rescuing the surplus food from different food providers and re-distributing to people in need. However, surplus food donation is a random process which varies with regard to quantity, time and place. Understanding the dynamics of food recovery and forecasting food donations using historical information has significant importance in inventory management and redistribution, particularly in reducing operational costs and achieving a sustainable and equitable distribution of inventory incorporating uncertainties in supply. This paper uses different modelling techniques including multiple linear regression, structural equation modelling and neural networks to explore the patterns and dynamics of food donation and distribution process for one of the largest food rescue organization in Australia. A set of significant indicators has been identified to describe the current food donation process, to predict daily average food donated by different food providers and also to anticipate the potential donation from a new donor which may appear in the network in the future. Results suggest that structural equation modelling and neural networks provide improved demand estimation when compared to conventional multiple linear regression. We also discuss the usefulness of these models in sustainable and equitable management of food recovery and redistribution.

1. Introduction

Although, most of the industrialized and developed countries produce enough food to feed themselves and the rest of the world, millions of people live with very low food security. Australia, being one of them, produces enough food to feed 60 million people, almost twice as their current estimated population [1]. However, recent research indicate that more than 1.9 million tonnes of food is discarded from the manufacturing and retail sector into landfill each year, and over 2 million people have low food security in Australia [2]. Most of the food they throw away is avoidable and could have been consumed if it had been managed better. This food waste and food insecurity problem is tackled by an ever-growing number of food rescue organizations in Australia (Foodbank, Food Rescue, OzHarvest, Secondbite, etc.) which collect surplus food from different food providers and redistribute it to welfare agencies supporting various forms of food relief. Foodbanks are not-for-profit organizations which act as a pantry to the charities and community groups that feed the hungry. They rescue food products, including perishable goods, incorrectly labelled items, etc., from different local sources such as farmers, manufacturers and retailers. These food products are then stored in warehouses, sorted, packed and sometimes processed before being delivered to welfare agencies or to specific delivery points, accounting for the perishability of the products and the requests of agencies. In essence, they function as aggregators and distributors of surplus food rescued from various sources. There are many other food rescue organizations that collect food from these foodbanks and different food providers, including groceries, supermarkets, cafes, farmers, wholesalers, small vendors, restaurants, etc., and directly deliver at no charge to agencies providing assistance to vulnerable men, women and children. Due to the perishability of food products collected, they are not stored in the warehouses, but are instead delivered on the same day itself. They operate trucks that visit food providers and agencies daily. The trucks start from a depot, collect food from food providers and deliver it to agencies, before

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returning back to the depot empty. The sequence of visits to agencies and food providers is determined based on the location of food providers and agencies, the quantity of food rescued and the demand of agencies. The frequency of visits of agencies during a week depends on the average daily availability of different categories of food. The efficiency of these food recovery operations depends on effective utilization of the recovered food with minimum wastage. *A major reason for wastage and inequitable distribution is that the quantity and category of food donated is unknown until observed upon the driver's arrival. The aim of the study is to analyze food donation data to help food rescue organizations to deal with this uncertainty.*

To address the uncertainty issues, it is important to understand how it affects the logistics and operation of food rescue operations. Unlike most logistical organizations, the operations of not-for-profit food rescue organizations are not solely cost driven. These organizations operate in the social interest and are therefore governed by fairness and equity considerations. Each welfare agency has a request (demand), a single product type or a combination of different product types, which is a function of the type of food assistance they provide (breakfast program for kids, community kitchens, food parcels, etc.), the size of the agency (number of people they support), frequency of service, etc. Ideally, agencies should determine and communicate their demand in advance so that food rescue organizations can effectively design the routes and equitably allocate the limited surplus food among the agencies. However, the type and quantity of food available at each food provider is unknown until observed upon the driver's arrival. In practice, in the absence of supply information, the decision maker designs initial routes minimizing the operational cost and the drivers make critical decisions regarding the delivery of rescued food to the agencies. Generally, the driver is expected to: (i) satisfy the agency's demand while reserving the supply for the other remaining agencies on the route and (ii) re-design the initial routes if the food available (different categories) at a food provider is insufficient to meet the demand of the agencies. Thus, uncertainty in the supply often leads to re-routing, higher operating costs, wastage of rescued food and unfair allocation of food. Hence, addressing these concerns are the major goals of many non-profit food rescue organizations.

The aims of the study are to 1) forecast the supply of different categories of food at different food providers, 2) identify parameters explaining the quantity of food supply and 3) investigate the applicability of different forecasting methods to predict the quantity of different types of food supply per day at each food provider. Understanding the pattern and availability of donated food is crucial in order to effectively plan and manage vehicle routes, and allocate different categories of food equitably among welfare agencies. The forecasting models developed in this study would better equip decision makers in anticipating the food availability, well before a journey starts. This would facilitate efficient operations and help in bringing down the operational costs incurred by food rescue organizations. Additionally, estimating the average daily availability of different categories of food would enable decision makers to understand the underruns (supply is less than required) and overruns (supply is greater than required). Thus food rescue organizations could effectively design the frequency of visit and schedule (assign into a particular day) of visit matching the supply and demand and minimizing waste. Data from a food rescue organization (Ozharvest, AU) was analyzed to develop models that will equip decision makers with tools to forecast the food supply distribution. The model incorporates information related to the observable characteristics of food provider, such as type, size, region (land-use, population and area) and day of donation (Weekday/Weekend). Several modelling specifications have been employed in this study, including Multiple Linear Regression (MLR), Structural Equation Modelling (SEM) and two artificial neural networks, namely, Feed-Forward backpropagation Neural Network (FFNN) and Generalized Regression Neural Network (GRNN). These models are used to estimate the average food donated per day per category per food provider using historical data provided by OzHarvest, Sydney. FFNN and GRNN are two groups of Artificial Neural Networks (ANN) that perform differently based on input variables. Both have their own advantages and disadvantages. While FFNN is sensitive towards the neuron interconnection weights and local minimum, GRNN gives a better approximation when the input variables are continuous. Another advantage of GRNN is fast learning and convergence to the optimal solution as the sample size increases [3]. In the proposed study, along with comparing the estimates of ANN, MLR and SEM, we intend to identify the best neural network approach for demand forecasting by considering two different types of ANN.

The remainder of the article is structured as follows. Section 2 illustrates the background and a brief literature review. The datasets used in this study are then explained, and the explanatory variables are discussed in Section 3. Section 4 presents a brief description of different forecasting methods. Experimental results from different models are discussed and compared in section 5. Conclusions and future research directions are discussed in the final section.

2. Background

There is considerable relevant literature discussing the role of forecasting techniques in estimating future demand using historical data in various domains. While most of them focus on areas like transport planning, supply chain management, weather forecasting, sales forecasting, economic forecasting, etc., very few discuss the use of forecasting techniques in estimating blood donation demand and supply [4,5], potential organ donation [6] and scarce resource consumption [7–9]. Despite its wide applicability, forecasting models received little attention in food rescue operations. While the recent few studies focus on optimizing collection and delivery schedules [10–14] and equitable allocation of rescued food [15,16], few studies addressed the need of forecasting the donation amount. Lien et al., 2014 [16] proposed a resource allocation model for a food rescue organization in Chicago, for effective and equitable allocation of rescued food, considering an egalitarian welfare utility function as an indicator of equity. They compared the performance of their allocation model in the case of uncertain supply with the case where all the supply are known prior to routing and found that the model performance, in terms of maximizing equity and minimizing wastage, can be improved if the supply is known prior to routing.

Phillips et al., 2013 [17] proposed an empirical model to estimate the total quantity of food rescued by Food Bank in north central Colorado. The authors described the food donation process using a peak over threshold model, where the events greater than zero were modeled using a Generalized Pareto distribution. The surplus food donated by food providers was modeled as a function of their type (grocer, manufacturer, individual and farm), and size. Their study focused primarily on understanding the gap between demand and supply and strategies to improve the total food rescued. However, they considered only the total amount of food rescued, rather than looking at the nutritional value and category of food rescued.

Davis et al., 2013 [18] analyzed the food rescue operations of Food Bank of central and eastern North Carolina. They discussed the use of time series forecasting techniques, moving average and exponential smoothing to forecast the amount of food donated per

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