



# Enabling Sustainable Consumption: Development of an Inventory Management Tool for Food Recovery

Chelsea Dean<sup>1</sup>, Fazleena Badurdeen<sup>1,2(✉)</sup>, and Kendra OoNorasak<sup>3</sup>

<sup>1</sup> Department of Mechanical Engineering, University of Kentucky, Lexington, KY 40506, USA

Badurdeen@uky.edu

<sup>2</sup> Institute of Sustainable Manufacturing, Lexington, KY 40506, USA

<sup>3</sup> Department of Dietetics and Human Nutrition, University of Kentucky, Lexington, KY 40506, USA

**Abstract.** The food supply chain presents numerous challenges from farm to fork resulting in over one third of all food produced going to waste. These challenges uniquely affect the level of food insecurity among regional populations. Food lost in the production and manufacturing stages of the supply chain are most influential in developing nations. Meanwhile the retail and consumer stages substantially affect food wasted in developed nations. The project described in this paper applies a systems-based approach to evaluate the inventory management needs for a charitable food recovery organization (FRO) and develop a tool for more effective management of recovered food. The capabilities to be incorporated in the tool are identified through an in-depth literature review and a current state assessment of the FRO's system. Influential relationships and feedback loops are examined to provide a central view of inventory assets, how they are acquired and dispersed. The easy-to-use tool is then developed to interface with existing data collection mechanisms at the FRO. The paper will detail the research involved and necessary steps taken to provide accurate sustainability and inventory reporting for the FRO for more effective food recovery. Limitations of the tool and potential improvement opportunities will also be discussed.

**Keywords:** Food Waste Recovery · Inventory Management · Sustainability Reporting

## 1 Introduction

More than 2.3 billion people around the world are food insecure while one third of edible food is lost or wasted [1]. The industrial economy has evolved and diversified over time, yet the process of linear production and consumption has remained largely unchanged. The United Nations Food and Agricultural Organization (FAO) describes food loss as any food that is disposed of before reaching the retail level of the food supply chain [2]. Food waste refers to the disposal of food at the retail and consumer level of the food supply chain (FSC). Food waste commonly occurs when fresh produce is not

aesthetically optimal for retail sales, food date labels are confused or misinterpreted, and food is unused or leftover from foodservice and households [2]. The cost of food waste was estimated at 1 trillion USD in 2014 making the need to address food waste a financial affair [3]. Furthermore, the environmental impact of food waste includes each resource consumed and all pollutants emitted to produce, process, transport and ultimately dispose of food fit for consumption.

Previous work emphasizes inventory management capabilities along the FSC to decrease food loss and waste [4]. Food recovery efforts can divert edible food from the FSC to mitigate waste, but research regarding the solicitation of web-based tools utilized within FROs is limited. Food rescue applications such as MealConnect enable donors to connect to FROs directly which necessitates an understanding of inventory capacity and stock levels. Work management platforms such as Smartsheet are used to track inventory and manage waste for FROs, but the financial constraint is not suitable for small-scale organizations. This project applies a systems-based approach to identify the activities of a local FRO and to create an inventory management tool that is easy to use and affordable. The tool will increase data transparency and complement the physical inventory management strategy used at the facility. Food waste solutions and FSC stakeholder claims identified through the literature review will supplement the tool requirements outlined by the FRO. This assessment facilitates defining local stakeholders, understanding how food waste is measured, and identifying relevant tool capabilities. Feedback from the FRO will validate the tool's features and the dynamic visualization of information. Limitations and potential improvement opportunities are described before conclusions are made.

## 2 Review of Sustainable Solutions for Food Waste

Linear consumption follows the 'take-make-dispose' model where resources are harvested or extracted to produce, manufacture, and distribute goods [5]. Businesses are observing higher resource prices, increased resource volatility and additional disruptions to supply chain operations. In terms of the industrial economy, circularity refers to an economy that is restorative or regenerative by design [5]. Food recovery presents an opportunity to improve circular economy (CE) practices by diverting waste from disposal channels to provide meals and surplus food items to those in need. The concept of CE requires the application of sustainable practices and innovation to remain viable over time [6].

In the Post-2015 Development Agenda, the UN adopted 17 Sustainable Development Goals (SDGs) as a global development framework [7]. SDG 12.3 aims to promote sustainable consumption by reducing food loss and food waste by 50 percent. A food waste index has been proposed by the UN, enabling institutions to accurately measure food waste [1]. Sustainable consumption is a challenge to the conventional form of consumerism that requires new solutions. Sharing economy solutions place providers in direct contact with consumers and eliminates the social stigma of food sharing [8]. Sharing economy solutions such as food recovery are enabled by transparency and routine practice. The food waste index can be used to establish best practices in measuring food recovery and food distribution for FROs.

Technological tools can improve FSC operations by increasing the accuracy of measuring material input, production output and waste generated [9]. Digital information sharing can integrate food waste management strategies across all stages of the FSC to collect, redistribute, and process food waste sustainably (see Fig. 1). Utilizing a systems-based approach for tool development will detail the methodology and research applied in the process. Additionally, the objectives and strategies to promote effective response are identified using a systems-based approach [10].

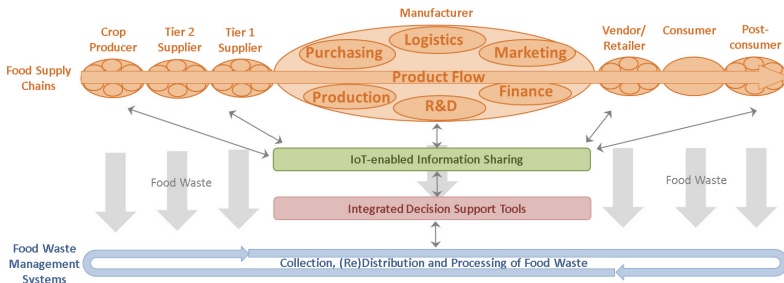


Fig. 1. Integrated Framework for Food Waste Prevention and Management [9]

### 3 Systems-Based Approach for Tool Development

The building block principle of systems modeling describes a model as consisting of one problem, or equation, and the dynamic forms in which that problem can be realized [11]. Simple systems contain one module and complex system models contain one or more module groups. This project uses a set of simple system models that represent the activities of a local FRO. The stakeholder diagram described in this section is used to determine the route of edible food waste and define influential stakeholders outside of the focal FRO. This diagram can be used to determine where any organization fits into the food waste recovery supply chain. The causal loop diagram discussed in this section identifies the internal operations and relationships in the focal FRO. These relationships are carried over into a stock and flow diagram to determine the key components used to measure food waste recovery.

**Defining Local Stakeholders.** Local food waste stakeholders (see Fig. 2) represent active participants in the FSC that directly relate to the focal FRO studied in this project. Food Waste Sources are organizations that produce both edible and inedible food waste. Food Recovery stakeholders recover food fit for human consumption and redistribute that food to feed people. Receiving Groups are the organizations that accept recovered food from Food Recovery stakeholders. Disposal Channels are the pathways for food waste. Finally, food recovery groups work to divert edible food from these disposal channels.

**Campus Kitchen and its Stakeholders.** Campus Kitchen (CK) at the University of Kentucky is a nonprofit student run FRO dedicated to reducing food waste and food

insecurity through action and awareness. In 2019 an estimated 126,350 surplus food tons were wasted in Kentucky due in part to food safety regulations that require immediate rescue response time [13]. Institutional FROs such as CK can act quickly to receive and distribute this surplus food while following the necessary food safety regulations. There are three key activities for CK volunteers – food recovery, meal preparation, and delivery. The CK program director has described volunteer roles and responsibilities that will be considered during tool development. Implementing new technology and a new process to capture inventory data was not feasible due to the additional training required and volunteer turnover. Shift leaders utilize a web-based survey to record the activities completed during their shift. An opportunity exists to automate the analysis process and provide side by side information on different inventory types. Automated inventory management systems allow organizations to save significant cost in terms of physical inventory counts, administrative errors, inventory tracking, and stock shortages [12].

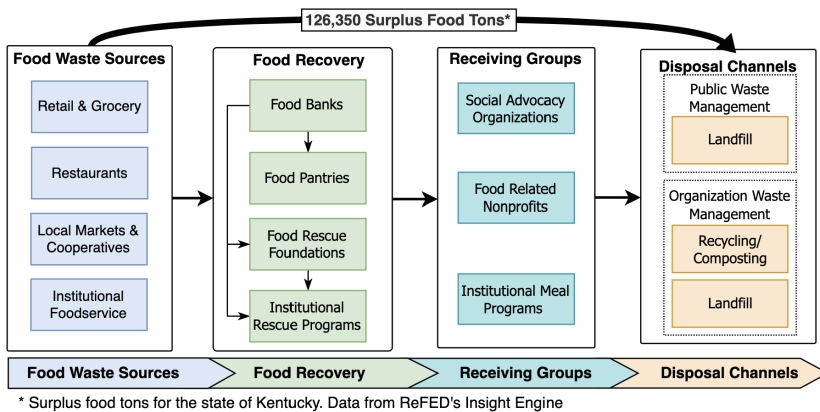


Fig. 2. Local Food Waste Stakeholders

**Causal Loop Diagram Construction.** With stakeholder relationships defined, the next step is constructing a causal loop diagram (CLD) to identify the critical path of CK operations. A CLD aids in visualizing how variables in a dynamically complex system are interrelated [14]. CLDs are structured by words and arrows to create a simple yet expressive representation of the relationships and feedback loops in a system (see Fig. 3). Words depicted on the CLD are variables that have value, which change over time. The arrows represent a positive or negative relationship between two variables. Multiple iterations of CLD construction were completed to identify a closed system boundary where the tool can measure key performance indicators [10].

**Designing the Stock and Flow Diagram.** A stock and flow diagram differentiates the parts of a system using variable definitions from the CLD. Business and inventory management use stocks and flows to describe the quantities in a system. A stock is the value of an asset at a particular point in time [14]. In Fig. 4 the amount of food accepted is

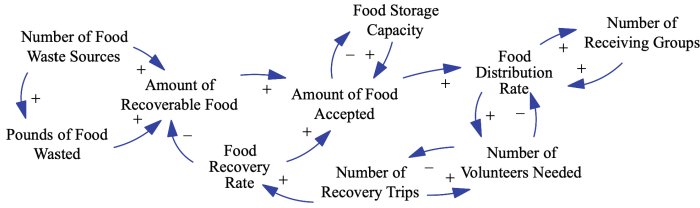


Fig. 3. Causal Loop Diagram of CK operations

the stock for CK. Flow variables are measured over an interval of time and describe the rate of change of a stock. The food distribution rate (see Fig. 4) describes the amount of accepted food that is leaving the system when meals are made. The food recovery rate refers to the amount of recoverable food that is accepted over time. The clouds in the diagram represent the sources and sinks of the process flow which are not directly measured in the system and do not impose limitations on the system.

A stock list will measure the level of inventory inputs and outputs [15]. The web-based survey completed at the end of each shift in CK captures the stock list data. Stock input is measured by the weight of food recovered. The weight of delivered food and food compost measure the stock output. Ingredients removed from stock for cooking are not included in the survey. This measurement method leaves a gap of information for food in the cooking process.

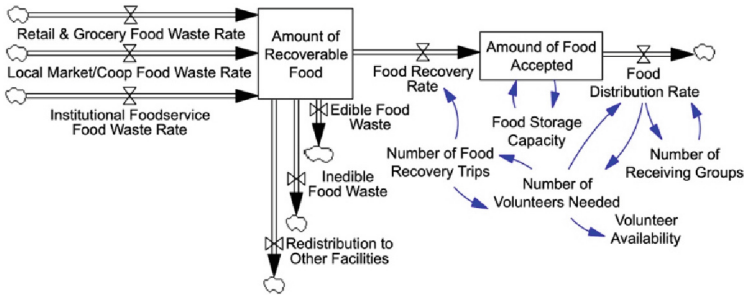


Fig. 4. Stock and Flow Diagram of CK Operations

### 4 Methodology for Tool Development and Testing

At the end of each semester, the executive team at CK is responsible for recording and analyzing food recovery and distribution data, currently done manually. The semester report includes four sections – food recovery, food distribution, social engagement and environmental impact. Using the tool developed will automate this reporting process and provide real-time data measured by semester, month, and day. This section describes the methodology used to automate the data analysis process.

**Determining Tool Capabilities.** Tool design will incorporate ad-hoc management practices. Ad-hoc management provides key criteria information based on what the organization's stakeholders deem necessary [16]. The tool will provide flexibility and clarity in the decision-making process by separating data by two concerns – inventory tracking and impact reporting. Advocates of ad-hoc views maintain that the separation of concern reduces the confusion caused by displaying all information in one view [16]. The dynamic inventory displays will consist of a monthly, daily, and location report. The impact report is a separate aspect view containing the financial, social, and environmental data to be used for the end of semester/semi-annual reporting.

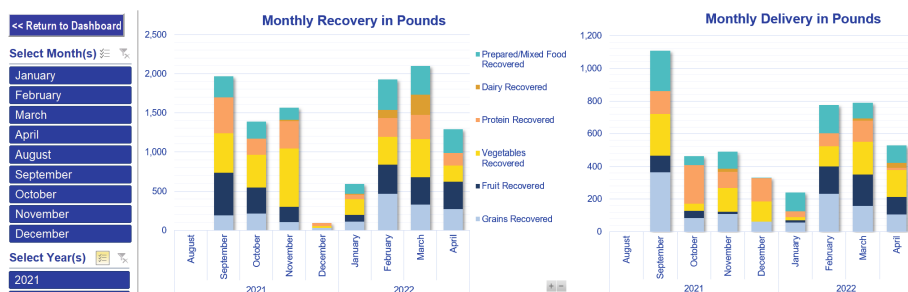
**Platform-Based Design.** Internal stakeholder experience with existing technology was the main determinant for the tool platform. The survey data is imported to Power Query in Microsoft Excel to clean up the data and apply simple mathematical operations where needed. The data transformation process includes removing columns that do not contain inventory information and renaming columns to signify the impact to inventory (i.e., grains recovered, meals delivered, and vegetables composted). The data is loaded to Excel where pivot tables are used to aggregate information and quantify inventory assets.

**Verifying and Validating Tool Specifications.** Industrial practices are increasingly reliant upon technological tools to enhance decision making. Data and visual accuracy are important to developers, users, and decision-makers. Verification and validation are used to determine whether a tool is correct [17]. Verification checks that a tool meets the design specifications. During development the tool was verified by loading small sets of survey responses to the tool and comparing those results to hand calculations. This process can be used for post-development verification. Validation confirms that the tool specifications meet the needs of the executive team and CK volunteers. Users of the tool were heavily involved in the development process and a final review of the tool will validate that the requirements have been met.

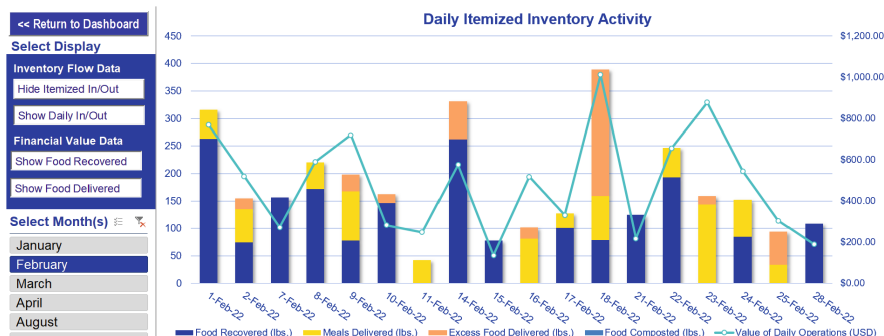
**Results.** The tool contains four displays as shown in Table 1. Each display contains pivot tables and charts to summarize survey responses based on concern. Inventory input and output data is contained in each report based on three levels of granularity – monthly, daily, and semi-annually/by semester. The timeframe for the data report is selected by the user. Additionally, the impact report contains the environmental and social influence of CK operations.

**Table 1.** Dynamic Displays in the Inventory Tool

| Dynamic Display | Concern  |
|-----------------|--|
| Monthly Report  | Overview of food recovery and meal delivery inventory constructed for the Director to compare monthly performance. (see Fig. 5)              |
| Daily Report    | Verification of daily recovery inputs and delivery/waste outputs for the purpose of inventory tracking and process improvement. (see Fig. 6) |
| Impact Report   | Determines the financial, environmental, and social influence of food recovery and distribution by semester/semi-annually (see Fig. 7)       |
| Location Report | Improves communication between internal and external stakeholders by aggregating monthly recovery and meal delivery data by location         |



**Fig. 5.** Inventory Tool Monthly Report



**Fig. 6.** Inventory Tool Daily Report

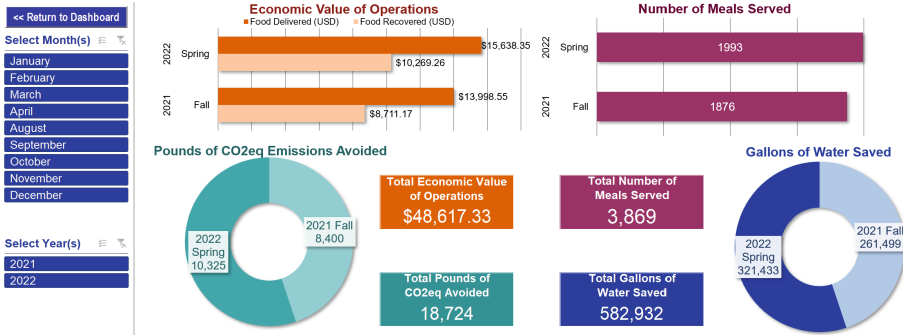


Fig. 7. Inventory Tool Impact Report

## 5 Conclusions and Future Work

The food waste problem is a complex issue that must be addressed using comprehensive strategies to understand the dynamic relationships impacting the FSC. Facilitating FROs reduces the amount of food wasted by diverting edible food from disposal channels and redistributing that food to people. Food recovery does not address the overabundance of food produced and served, but it promotes a circular economy by eliminating waste. Understanding the problem and enabling sustainable consumption requires recognition of the multidisciplinary nature of the FSC as a system. Food waste research regarding FROs is spread across the entire food supply chain and is often generalized as an act of good will. Current web-based tools and smart phone applications have a high potential for expanding food rescue measures, but a scalable application that addresses all FRO activities requires further investigation. This project aims to contribute to food waste management research through the scope of an FRO inventory management system and encourage further academic research regarding scalable low-cost strategies that increase the intervention FROs have on food waste.

The systems-based approach used to develop this tool adapts traditional inventory management techniques to fit within the constraints of a charitable FRO. The tool features metrics defined by food waste stakeholders to quantify the economic, environmental, and social assets of the organization. The results of this tool provide an automated view of inventory activity with generalized sustainability indicators. Potential improvements to the tool include—modeling the relationship between volunteer activity and inventory data, applying a greenhouse gas index to increase environmental impact reporting, and tracking the food category types to determine where food processing activities could extend shelf life or increase nutritional value.

## References

1. World Health Organization: The State of Food Security and Nutrition in the World 2021: Transforming food systems for food security, improved nutrition, and affordable healthy diets for all. Food & Agriculture Organization (2021)



2. United Nations FAO: What is food loss and food waste? <https://www.fao.org/food-loss-and-food-waste/flw-data>. Accessed 01 Feb 2022
3. United Nations FAO: Food Wastage Footprint. <https://www.fao.org/nr/sustainability/food-loss-and-waste>. Accessed 30 Mar 2022
4. Bajželj, B., Quested, T.E., Rös, E., Swannell, R.P.: The role of reducing food waste for resilient food systems. *Ecosyst. Serv.* **45**, 101140 (2020)
5. MacArthur, E.: Towards the circular economy. *J. Ind. Ecol.* **2**(1), 23–44 (2013)
6. Pistikopoulos, E.N., Baratsas, S., Avraamidou, S.: A systems engineering framework for the optimization of food supply chains under circular economy considerations. *Sci. Total Environ.* **794**, 148726 (2021)
7. Brundtland, G.: Report of the World Commission on Environment and Development: Our Common Future. United Nations General Assembly Document A/42/427 (1987)
8. Richards, T., Hamilton, S.: Food waste in the sharing economy. *Food Policy* **75**, 109–123 (2018)
9. de los Mozos, E., Badurdeen, F., Dossou, P.: Sustainable consumption by reducing food waste: a review of the current state and directions for future research. *Procedia Manuf.* **51**, 1791–1798 (2020)
10. Lee, C.K.M., Ng, K.K.H., Kwong, C.K., Tay, S.T.: A system dynamics model for evaluating food waste management in Hong Kong, China. *J. Mater. Cycles Waste Manage.* **21**(3), 433–456 (2018). <https://doi.org/10.1007/s10163-018-0804-8>
11. Burgess, T.: Systems analysis and modeling: a macro-to-micro approach with multidisciplinary applications. *J. Oper. Res. Soc.* **53**(12), 1398 (2002)
12. Aro-Gordon, S., Gupte, J.: Review of modern inventory management techniques. *Glob. J. Bus. Manag.* **1**(2), 1–22 (2016)
13. ReFED's Impact Calculator. <https://insights-engine.refed.org/impact-calculator>. Accessed 04 Apr 2022
14. Sterman, J.: *Business Dynamics*. McGraw-Hill Inc., United States (2000)
15. Davis, E.: Inventory flow analysis. In: Swamidass, P.M. (eds.) *Encyclopedia of Production and Manufacturing Management*. Springer, Boston (2000). [https://doi.org/10.1007/1-4020-0612-8\\_458](https://doi.org/10.1007/1-4020-0612-8_458). Accessed 30 Mar 2022
16. Hepworth, A., Misopoulus, F., Manthou, V., Dyer, R., Michaelides, R.: Exploring ad-hoc portfolio management: does it work, and is it the flexibility that supports project portfolio management? *Procedia Comput. Sci.* **121**, 345–355 (2017)
17. Sargent, R.: Verification and validation of simulation models. In: *Proceedings of the 2010 Winter Simulation Conference*, pp. 166–183. IEEE, Baltimore MD (2010)

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