UMSAEP Project Report

Developing Data-Driven Optimization Capabilities for Agribusiness Supply Chains in South Africa

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Research Activities Prior to the UWC Visit

Our collaborative research started in the Fall of 2019 to address the data-driven decision needs for configuring an end-to-end food supply chain. The focus was on the food supply chain configuration problem (FSCCP) with supply-side uncertainties to capture the impact of supply risks and disruption, which are ubiquitous in a food system. For instance, production yield is often uncertain due to extreme weathers and natural disasters; supply capacity may fluctuate due to workforce availability; transportation lead time may vary due to port congestion and driver shortage.

Although Dr. Li's originally planned visit to the University of Western Cape (UWC) in Summer 2020 was postpone due to the Covid-19 pandemic, our research effort continued. A new optimization model was developed to extend the existing FSCCP model of (Li, Li et al. 2021) by explicitly considering stochastic lead time as a measure of the supply-side risk. To handle the complexity and computational challenge of the model, a genetic algorithm (GA) was developed to obtain high quality solutions in reasonable computational time. Computational study shows that the consideration of supply risks significantly changes the optimal supply chain configuration with increased safety stock cost. A manuscript entitled "Optimizing the Configuration of Agri-food Supply Chains with both Demand- and Supply-Side Risks" is in progress as part of the deliverable of the project.

In April 2022, the research team worked on and submitted a proposal for a U.S. Department of State grant (funding opportunity number: PAS-ZAF-FY22-02), entitled "Climate-Smart Decision-Support for Farms and Agribusiness in South Africa". This proposed project aims to develop and implement an AI-based decision-support tool that enables climate-smart data-driven farm planning and agribusiness operations in South Africa. It has three main goals: (i) efficient utilization of resources (land, water, labor, etc.) to optimally balance the tradeoffs among yield, cost, and environmental impact, e.g., greenhouse gas (GHG) emission; (ii) better matching production/supply with demand by considering market factors including demand, diet/nutrition need, accessibility, and equity; and (iii) improved food supply chain operations for adaptation to (reactive) and preparation for (proactive) climate change. Once funded and successfully executed, this project will assist small- and medium-sized farms to use land and water resources more efficiently. It will also provide actionable decision-support for food processors, non-profit organizations, and policymakers to better match food production and supply with demand, coping with food insecurity. Broader impacts of the project include better triad engagement and collaboration between farm-government-academia, and capacity building for AI-enabled agribusiness supply chains in South Africa.

The proposal was not funded with no concrete evaluation or feedback received. However, it laid the groundwork and provided guidance the focus of Dr. Li's visit to UWC in Summer 2022.

Activities During Dr. Li's Visit to the UWC

The main activities during Dr. Li's visit to the UWC include: two research seminars, two farm visits to the Mahni Gingi Foundation and the Middlepos Farm, and a proposal for the 2022 UMSAEP grant.

Research Seminars

Dr. Li gave two research seminars to the UWC faculty and student with details below. Both seminars were well-received by the participants.

Seminar Topic 1: Optimizing the Configuration of Agribusiness Supply Chains

An agribusiness supply chain is a complex system with unique characteristics and challenges. The need for efficient, quality, and resilient decision-support through all stages of a food chain: growing/production, processing, storage, distribution/transformation, and sales, create abundant opportunities for the application of prescriptive analytics, or data-driven optimization. In this seminar, I will focus on the general class of food supply chain configuration problem (FSCCP), which addresses the tactical level mode/option selection and system-wide safety stock placement decisions. An outline of my talk is provided below:

- Introduction to Agribusiness Supply Chains
- Overview of the Data-Driven Optimization Approach
- Food Supply Chain Configuration Problem
  - Problem setting and assumptions
  - Optimization modeling framework and formulation
- Applications
- Grape supply chain
- Rice supply chain
- Research Opportunities

Seminar Topic 2: Vehicle Routing – Problems, Models and Applications

A vehicle routing problem (VRP) is an extension of the famous travelling salesman problem (TSP) by considering multiple vehicles to serve customers. VRP and its variants have numerous applications in various industries, including logistics/transportation, healthcare, food/agriculture, and telecommunication, among others. In this seminar, I will introduce the broad family of VRPs with classification schemes, and focus on how to build mathematical programming models for VRPs. I will also showcase some of my recent research in this area as application examples. An outline of my talk is provided below:

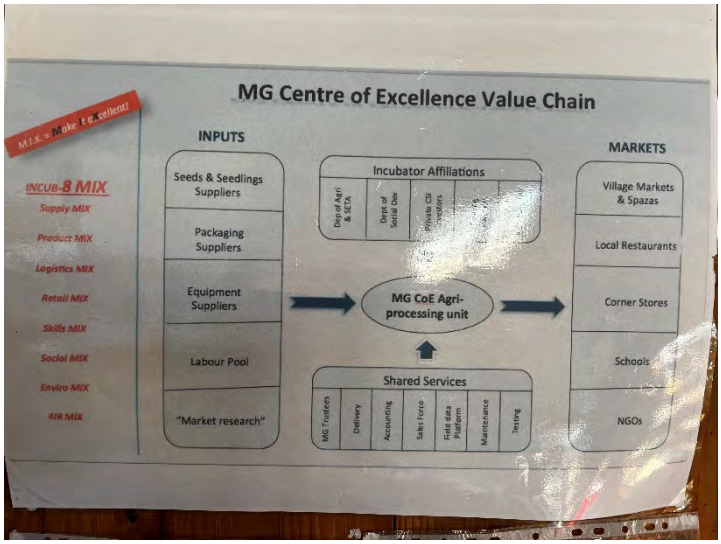
- Introduction and Motivation for Studying VRP
- Variants of VRP and Classification Schemes
- Building Integer Programming Models for VRPs
- Application Examples:
  - Food pickup and delivery
  - Technician routing and scheduling
  - Applications in telecommunication
- Research Opportunities

Farm Visits: The Mhani Gingi Foundation

On July 26, 2022, Dr. Li and Dr. Jokonya visited the Mhani Gingi Foundation, and met with Mrs. Lillian Masebenza (founder of the Mhani Gingi Foundation) and Mrs. Tabisa Mahlathi (operations manager). Mrs. Masebenza and Mrs. Mahlathi introduced the mission and history of the Mahni Gingi Foundation, with its primary business model and operations.

Mhani Gingi is a non-for-profit organization established in 2007 that strives to provide innovative business solutions which are sustainable and contribute towards alleviating poverty in South Africa. Mhani Gingi empowers vulnerable groups in the community create sustainable livelihoods for themselves. This is achieved through urban agriculture, community food gardening and social enterprise solutions which provide skills training and income generation for our beneficiaries, as well as food for consumption.

Mhani Gingi is in a unique position in the food supply chain to connect food producers/suppliers to consumers, especially the disadvantaged population groups including the low income, women, and children. Thus it shares a similar role with that of the foodbanks we have in the U.S., but it is unique in the fact that it also owns and operates community food gardens in an urban setting. It was also impressive to see their creative solutions to include disabled (differently abled) people in urban agriculture. It currently works with 25 differently abled adults who maintain two community food gardens and share the produce with other residents in the area.



While Mhani Gingi has been quite successful fulfilling its social responsibilities, it has been experiencing significant challenges on the business and operational sides since the Covid-19 pandemic. Due to shrink of government funding, shortage of labor, and recent increase of fertilizer and fuel costs, its profit margin has become very thin, which significantly impacted the economic viability of Mhani Gingi.

We discussed the following decision needs at Mhani Gingi for which our research can help:

- **Dynamic Produce Portfolio Selection**: How to select the right set of produce to grow and sell in different times of a year while considering the varying market factors such as demand, price (for selling) and cost (for procurement)?
- **Production Planning and Resource Utilization**: How much of the produce (selected) to grow with the limited capacity of space, water supply, and labor?

Farm Visits: The Middlepos Farm

On July 28, 2022, Drs. Haitao Li, Osden Jokonya, and Ms. Lisle Svenson visited the Middlepos Farm, and met with Ms. Ingrid Lestrade and Ms. Louise Leher (founder of the Middlepos Farm). Similar to Mhani Gingi Foundation, the Middlepos Farm was established was its mission serve the disavantaged people, especially the women and children living the nearby villages. Many of these women experienced domestic violence with psychological trauma, for whom the Middlepos Farm not only provides employment opportunites, but also a haven for mental and psychological healing. It has educational and learning facilities and equipment for after-school activities of children, while waiting for their moms working at the farm.

One advantage of Middlepos Farm is its abundant over 70 hectares' land with established vinyard to grow some of the favorable grapes in the region. It also has its olive garden and is able to produce high-quality olive oil. However, the reduction of government support during the pandemic and increasing fertilizer and transportation cost have created significant changes for Middlepos Farm to be economically sustainable.

The do not have a sound business strategy or appropriate supply chain plan in place to support its sourcing/procurement, production, and distribution operations. The lack of activity-based-accounting (ABC) makes it difficult to understand the cost-of-goods-sold (COGS) of their products. For example, Middlepos Farm supplies grapes to a local wine-maker, whose brand-named red wine enjoys high reputation with

decent price in the market, yet little credit or profit region was attributed to Middlepos.

As a starting point, the research team planned to help Middlepos Farm address their produce portfolio and crop production/rotation decisions, which aligns well with the research work with the Mhani Gingi Foundation.

2022 UMSAEP Proposal

The knowledge and information collected during the two farm visits provided guidance for the research team's focus and plan moving forward, which led to a new 2022 UMSAEP proposal entitled "Climate-Smart Decision-Support for Farms and Agribusiness in South Africa". We now had an expanded team that included Dr. Noel Aloysius, a crop scientist, from UM – Columbia.

The overarching theme of this project is to develop and implement data-driven decision-support tools that enable climate-smart farm planning and agribusiness operations in South Africa. It aims to achieve the following goals:

- **Efficient utilization of resources** (land, water, labor, etc.) to optimally balance the tradeoffs among yield, cost, and environmental impact, e.g., greenhouse gas (GHG) emission.
- **Better matching production/supply with demand** by considering market factors including demand, diet/nutrition need, accessibility, and equity.
- **Improved operations** for adaptation to (reactive) and preparation for (proactive) climate change.

Recent studies advocating climate-resilient food systems in South Africa have identified several pathways for researchers, practitioners and policymakers: (i) to build integrated food systems including the end-to-end agribusiness supply chain from production, processing, distribution and consumption (demand and nutrition needs) (GCRF-AFRICAP 2022); (ii) to combine soil science with farm planning and agribusiness operations in connection with the food markets (Dougill, Hermans et al. 2021). This proposed project is a timely study to answer this call. The following groups of stakeholders will participate in and benefit from this project: small- and medium-size farms, food processors/distributors, and policymakers.

The figure below shows the logic model of this project. The research team will conduct interviews with key stakeholders and subject matter experts (SMEs) from small- and medium-sized farms, and organizations including Mhani Gingi Social Entrepreneurial Network, FANRPAN, and the Agriculture Research Council (ARC). Data will be collected from various partners and sources about land use and availability, resource availability (water, fertilizer, and labor), estimation of crop yields, and the food market (demand, price, and nutrition needs). The main research efforts will focus on the development and implementation of advanced analytical techniques in AI for data-driven decision-support with two main outputs: (i) a solution to optimize crops portfolio, rotation, and harvest planning; and (ii) a solution to optimize the design of end-to-end agribusiness supply chains. Broader impacts of our work include the development of new courses on climate-smart food and agribusiness supply chains and outreach to communities lacking food security. In the short-term, the outcomes of this project are expected to improve the utilization of land, water,

and labor resources; better match food production/supply with demand with reduced food loss and waste; and increase the profitability and return-of-investment (ROI) of small- and medium-sized farms. In the medium-term, our work will improve the use of technologies and methods for increasing yields, controlling food loss and waste, and reducing GHG emissions; improve food accessibility and nutrition to feed those in hunger; and improve the efficiency, resilience, and sustainability of the food supply chain networks. The long-term impacts of this project include evidence-based policy for efficient, resilient, and sustainable food systems; coalition and collaboration between the research community, private sector, and government; and improved food security for coping with hunger.

Ways Ahead

The outcome of this first phase of the project of multi-disciplinary teams focusing on few small-scale farmers will be expanded to different districts in Western Cape before being replicated to other province in countries as part of the FARNPAN collaboration. The project is involved in rolling out digital marketing training for small scale farmers in order to help them have easier access to market at a lower cost and better prices than the normal channels for their products. The project is adopting a bottom-up approach where small-scale farmers identify their needs which results in stronger purchasing power than the top-down approach used by most government agencies. More than 100 small-scale farmers have benefited from the digital training with the project, who are also expected to be rolled out to other provinces in partnership with stakeholders. The transformation of the food systems will only be feasible if challenges of digital divide is addressed from the small-scale farmers perspective. Small holder farmers empowered with such digital marketing technology provides the foundation for data-driven decision-making as part of the sustainable Food System 4.0.

Situation: Crops in Africa are almost 95% rainfed, with very little cropland being irrigated. Environmental variations and climate change of all kinds: higher temperatures, changing precipitation patterns, and increasing frequency of extreme weather events, impair the four pillars of food security, i.e., availability, access, utilization, and stability. South Africa, in particular, is expected to experience a significant decrease in renewable water supply and has been classified to be one of countries with increased water stress. Additional challenges include poor market access and increasing cost of production and labor. Most of the existing research has focused on addressing the effects of environmental variability on food production and has been conducted in a siloed way without considering the interconnections and cascading effects of different functions and stages in an end-to-end food supply chain.

Inputs	Outputs		Outcomes -- Impact		
	Activities	*Participants*	*Short*	*Medium*	*Long*
Data • Land use and availability • Availability of resources: water, fertilizer, and labor • Yield of crops • Food market data including demand, price and nutrition needs • Current Mhani Gingi Social Entrepreneurial Network consisting of Agri-Processing Hub, Satellite Community of Food Stations, and growing network of households **Researchers** • PI and Co-PIs at UMSL, UWC and MU • Two Master students and one PhD students **Partners** • Small- and medium-size farms • Mahni Gingi Social Entrepreneurial Network • FANRPAN • ARC	**Research** Develop and apply data-driven decision-support models and tools to better plan for their production, distribution, and sales in an end-to-end supply chain: • Optimizing crops portfolio, rotation and harvest planning with considering market demand, price and nutrition needs; • Optimizing the design and configuration of an end-to-end agribusiness supply chains to better match food supply with demand while reducing food loss and waste. **Educational and Outreach Efforts** • Develop new courses on food and agribusiness supply chains • Outreach to and collaborate with industry partners	**Research** • PI and Co-PIs at UMSL, UWC and MU • Two Master students and one PhD students **Educational and Outreach Efforts** • Graduate students • Faculty at UMSL, UWC and MU • Small- and medium-size farms • Mahni Gingi Social Entrepreneurial Network • FANRPAN • ARC	• Improved utilization of resources (land, water and labor). • Better matching production/supply with demand with reduced food loss and waste • Improved return-of-investment (ROI) of small- and medium-size farms	• Improved use of technologies and methods for increasing yields, controlling food loss and waste, and reducing GHG emissions • Improved food accessibility and nutrition to feed those in need • Improved end-to-end food supply chain network connecting growers/producers, processors, logistics/transportation providers, wholesalers/retailers	• Evidence-based policies for efficient, resilient, and sustainable food systems • Coalition and collaboration between the research community, private sector, and government • Improved food security for coping with hunger

Assumptions
The research team will work closely with partners and stakeholders to define and scope the optimization problems to be addressed, collect the needed data, and to seek their inputs and feedback on the solutions and recommendations coming out of this project.

External Factors
One external factor beyond the researchers' control can be another wave of the COVID pandemic, which might disrupt the progress of the project, and create additional challenges of the food system.

Deliverables and Summery

The deliverables of this project include:

- This Project Report
- A working paper targeted at top journals such as Transportation Research: B, International Journal of Production Economics, etc.:
  "Optimizing the Configuration of Agri-food Supply Chains with both Demand- and Supply-Side Risks", 2022, Duxian Nie and Haitao Li, Working Paper, University of Missouri – St. Louis.
- Factors affecting the adoption of big data technologies in Agri-food Supply Chains by Small holder farmers, 2021, Osden Jokonya, Working Paper, and presentation, etc.

The research team thanks the continuing support of UMSAEP program. Moving forward, we will be working with Dr. Jejung Lee and Dr. Sejun Song at the University of Missouri – Kansas City with their expertise and contribution in sensors and GIS for land and water use. We plan to apply for an external funding opportunity from, e.g., NSF, USDA NIFA, among others.

References

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