# Adapting food supply chains in Smart Cities to address the impacts of COVID19 a case study from Guadalajara metropolitan area

Barbara Baena
Ph.D. in Information Technology
CUCEA *Universidad de Guadalajara*
Zapopan, JAL, MX
barbara.baena5025@alumnos.udg.mx

Cecilia Cobian
Ph.D. in Information Technology
CUCEA *Universidad de Guadalajara*
Zapopan, JAL, MX
cecilia.cobian9099@alumnos.udg.mx

Victor M. Larios
*Smart Cities Innovation Center*
*CUCEA*
*Universidad de Guadalajara*
Guadalajara, JAL, MX
victor.m.lariosrosillo@ieee.org

Jose Antonio Orizaga
*Smart Cities Innovation Center*
*CUCEA*
*Universidad de Guadalajara*
Guadalajara, JAL, MX
jose.orizaga@academicos.udg.mx

Rocio Maciel
*Smart Cities Innovation Center*
*CUCEA*
*Universidad de Guadalajara*
Guadalajara, JAL, MX
*ma.maciel@academicos.udg.mx*

Marco Perez Cisneros
Department of Electronics
CUCEI
University of Guadalajara
Guadalajara, JAL, MX
marco.perez@cucei.udg.mx

J. Raul Beltran-Ramirez
*Smart Cities Innovation Center*
*CUCEA*
University of Guadalajara
Guadalajara, JAL, MX
jrbeltran@cucea.udg.mx

***Abstract*—This article focuses on the food supply chain and aligns with the United Nations Sustainable Development Goal of Zero Hunger. They are looking to avoid food waste where Smart Cities must work. Food waste requires innovation with technology to change consumer's behaviors, efficient supply chain management, and innovative food production systems not to harm the environment. Among the economic impact, water and carbon footprint** affects **vital performance indicators into a Smart City. Hence, this work considers water and carbon footprint, as well as economic impact. We contribute to the Smart Cities, providing a multi-Agent simulation able to be scaled with an ontology with the purpose to plot different scenarios to stakeholders in a Smart City and help to avoid food waste situations. To simplify the simulation, as preliminary work, we used a typical food in Guadalajara Metropolitan Area, which is a Taco. The model covers a community in the Zapopan Municipality, where a developed urban study is the first proof of the system's concept. Furthermore, based on the simulation scenarios fed with real, local data, we discussed how we can integrate this multi-agent platform to face COVID-19. Finally, we want to help family businesses on the food supply chain using information technologies and applying digital processes to better adapt to new operation rules since COVID-19 to fight food waste since COVID-19.**

***Keywords*—Smart Cities, Multi-agent systems, Simulation, Ontologies, NetLogo, FoodWaste, Water Footprint, Carbon footprint***

## I. Introduction

Today, Smart Cities are involved in an unprecedented event, a pandemic that has impacted the world economy and how we live in cities. A Smart City has many dimensions; it is a complex system to be modeled. The health impact is interrelated with economic, labor, and food production. Therefore, it impacts the environment with a CO2 and water footprint at a cost of producing food. This work is also ~~is~~ concerned about the United Nations Sustainable Development Goal (SDG) (number two) related to zero hunger. As cities grow their population, we need innovation on the food systems to become more efficient and sustainable to avoid food waste. That is the case of the Guadalajara Metropolitan Area (GDL), where 4.6 Million People demand food every day. Besides, when living in a pandemic, with a lack of food sector small business digital transformation processes, the balance in the supply chain breaks and significantly impacts GDL.

On the other hand, one of the Smart Cities' characteristics related to the use of Information Technology is its capacity and resilience to new situations seeking balance in a complex system's dimensions. From a Smart City perspective, food impacts dimensions as the environmental footprint, healthcare, economics, and City Infrastructure for mobility and Storage. Hence, the food system's innovation has an impact on other Key Performance Indicators to reach the quality of life in a Smart City.

This article takes the perspective of analyzing the Supply Chain of the primary food sector and behavior of consumers in GDL, and contributes as a model to other cities with similar conditions. We propose simulation tools that allow the review of scenarios to evaluate the impacts on the supply chain, especially on COVID-19 circumstances help to avoid food waste. The simulation allows integrating possible solutions in the different Smart City modes affected Key Performance Indicators such as economy, jobs, environment, and healthcare. Finally, in our discussion, we will introduce some possible solutions with Information Technologies able to connect to our simulation platform to help in the innovation for the food sector to adapt and reduce food waste in GDL.

The impact on the supply food chain due to COVID-19 is generalized over the world [1]. Some studies on countries like the United States provide several use cases considering different key players as farmers, retailers, and consumers [2]. Scenarios for the Gross Domestic Product impact of COVID-19 spread for that region [3] that explain possible recover scenarios and list possible solutions for this industry.

Based on the state Gastronomic Chamber in Jalisco, the industry was growing more than double the country's economic growth rate. During 2018 in Mexico, the growth was 3 to 4%, and gastronomy business growth was more than 7%. On Jalisco, this industry generates 70,000 jobs [4]. The Jalisco region's negative impact appeared in local newspapers, and reports of Chambers of Commerce related to food, including interviews with experts on small businesses in the region [5]. Sales decreased 90%, 15% of closures, 5% of total business are small or family business that generated 10,000 jobs (4,000 were able to recover their job in the retail industry or grocery shops). Challenges:

- The population will have less money to spend, and businesses have to adapt prices on menus.
- Small businesses increased the use of Information Technologies platform as UberEats, Rappi, SinDelantal, a but 30% use fee(s) reduces revenue from small businesses.
- Each business will need to create a plan considering Jobs, processes, and supply chain.
- Raw materials will have, in some cases, higher costs.

## II. Problem Statement

### A. Food Supply Chain

From November 2019 onwards, a worldwide catastrophe occurred that affected the inhabitants of nations around the world. A virus appeared in China, which spreads to all geographies. The virus is hazardous to humans since it causes irreversible damage and death through symptoms similar to the flu. The people, especially the vulnerable groups, suffer asphyxia, severe pain, and very high temperatures. As a result of this and as a precautionary measure, the population is required to stay confined at home. Mexico was no exception, and from March 2020 onwards, the confinement began to shutdown non-essential activities. Indeed, the food supply chain is severely affected since the consumption behavior changed with COVID-19 shutdown measures.

This chain typically involves farmers in the countryside and the main supply markets in the cities. In Mexico City, one of the main markets is La Merced. This market supply the city with products such as potatoes, beans, corn, tomatoes, carrots, chili, pumpkins, apples, peaches, avocados, and even flowers.

Jalisco has the Abastos market of supplies, and the products they offer are fruits and vegetables and meats and cheeses. However, the food production areas in Jalisco supply not only the GDL area but, also an important economic sector that exports to other states in Mexico and other countries.

Following the food chain, after production and commercialization of raw materials in these markets, then we have food preparation. This work aims to cover as a first step, a simulation for small businesses disbursed around Mexico, which are the Taco's Shops or "Taqueria." To create a model first, we drive a simulation on one of the seven municipalities integrated at the GDL Metropolitan area, known as Zapopan. Figure 1 illustrates the Taqueria family business located ~~in~~ on street corners of the main neighborhoods. This type of small business represents 80% of the economic activity in the food sector in neighborhoods.

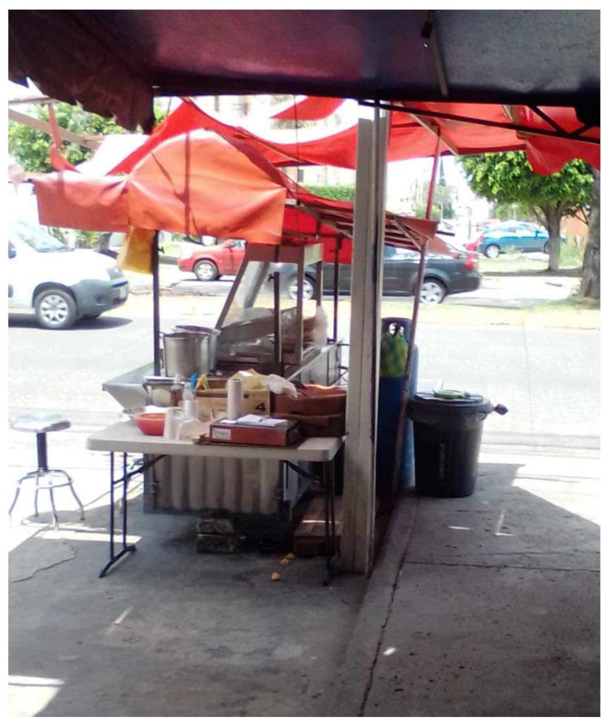


*Figure 1. A small taqueria business on the street*

Components of a taco dish are tortilla (based on corn fluor), beef meat, onion, and coriander. Those elementary four components involve local farmers for beef, corn, and vegetables. For these components, figure 2 shows what an authentic taco dish on the family taquerías looks like. For our simulation purposes on food waste impact of the environment, figure 3 shows the main variables this work will focus on for the tacos. During COVID-19 and social distance, sales declined because businesses needed to adapt to new consumer behaviors in all supply chains.

*Figure 2. Taco dish and principal components.*

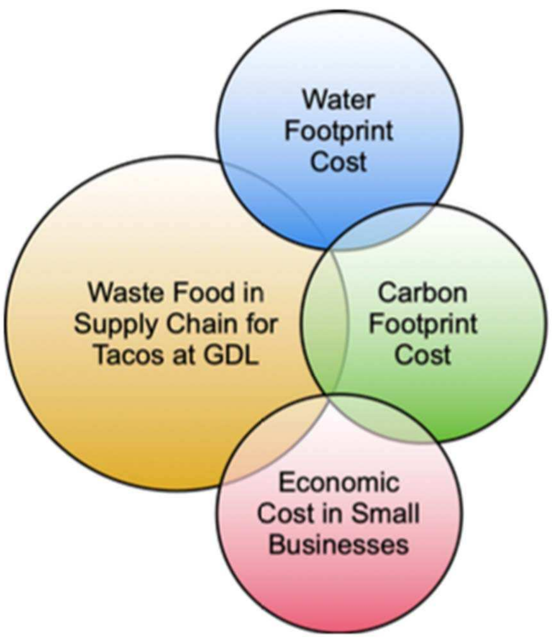



*Figure 3. Three main variables to survey on tacos food waste.*

The weeks that everybody needed to stay at home in isolation, sales decreased 90% during those three weeks. Most of the small businesses where closed, then they return to be open, but sales continued to have 40% less than the previous year [5]. We have calculated consumption in grocery shops. The impact on farmers with these decreases, calculations reflect those tons of wasted food; if we add the waste of energy to produce that food and the effect on hybrid and carbon footprint the problem looks phenomenal.

Table 1 shows a summary of the impact and conversion to water and carbon footprint [6,7,8] in numbers.

.

*Table 1. Impact on three variables for tacos waste estimation during COVID-19 shutdown*

| Raw material | COVID Impact -40% sales kg | 100 taquerias Kg of raw materials | Tons of food | H2O liters | CO2 kg |
|---|---|---|---|---|---|
| Tortilla – Corn | 448 | 44800 | 44.8 | 40320 K | 89.6tons |
| Beef | 280 | 28000 | 28 | 434k | 1.008tons |
| Onion | 56 | 5600 | 5.6 | 1120k | 224 |
| Green Tomato | 560 | 56000 | 56 | 10080 k | 112tons |

To look at the different components of a taco, we also estimated by component the water and carbon footprint shown in figures 4 and 5. As a remark, we highlight the beef cost in CO2 and water consumption plus than four times compared with vegetables, and hence, if we cannot reduce this environmental cost for beef, at least we can start avoiding to have wasted on it.

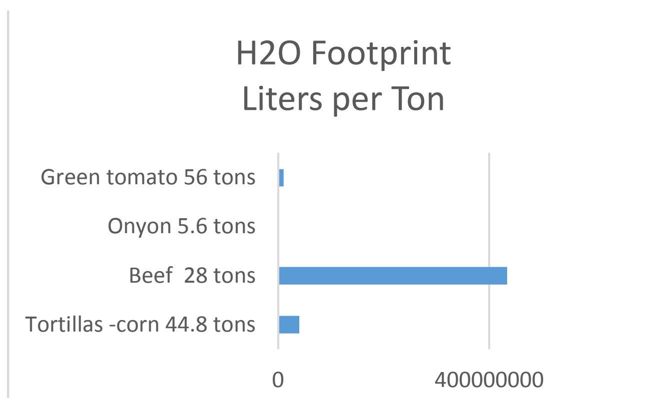



*Figure 4. Water footprint estimated for wasted tacos by components during COVID-19*

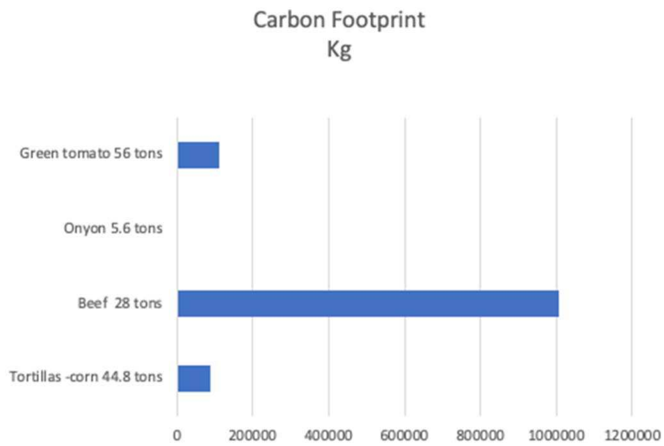



*Figure 5. Carbon footprint estimated for wasted tacos by components during COVID-19*

*Table 2. Economic estimation for wasted tacos in COVID-19*

| **Item to buy** | **Kg bought by day** | **$ spent by day 350 tacos= m** | **$ spent by Month 20 days** |
|---|---|---|---|
| Tortillas-corn | 14 | $196.00 | $3,920 |
| Beef | 8.75 | $1,478.75 | $29,575 |
| Onyon | 1.75 | $17.50 | $350 |
| Coriander | .005 | $63.00 | $1,260 |
| Green tomato | 17.5 | $315.00 | $6,300 |
| **SUBTOTAL 100 tacos->** | | $2,070.25 | $41,505 |
| Revenue (TotalSales - Cost)-> | | $7,245.87 | |
| | | | |
| Rent by day | $ 233.33 | $234.00 | $4,680 |
| Salaries by day | $260.00 | $260.00 | $5,200 |
| COVID—19 req | $50.00 | $50.00 | $1,000 |
| Government permission | $41.66 | $45.00 | $900 |
| Spend 100 tacos-> | | $2,659.25 | $53,185 |
| Revenue (TotalSales - Cost)-> | | $2,240.75 | |
| ***1 TACO cost MXN $14*** | | | |

Table 2 provides an idea of the economic impact of wasting 100 small business selling tacos, every day with a cost in MXN Pesos of 53.18K that is approximately equivalent to **2.4K USD** that the food supply chain is losing every month per one small business that sells "tacos." Guadalajara metropolitan area has more than 90,000 taquerias[14], so lost estimation is 90000 multiplied by 2400 USD per month: 216M USD lost sales. 1500 to 2000 employees have lost their job due to this impact on sales.

With this example, we could scale to any typical food in any country around the world, such as the small business food vendors like HotDogs in the United States, or Kashmiri Alo Dum found on street corners in India.

### B. *State of the Art*

Based on an analysis made by McKinsey&Company for the United States back in 2008, . Large companies may recover within four years in GDP, while it took six years for small businesses. "Many may never reopen." Based on a survey done by Global institute and Oxford Economics [6] on the accommodation and food services sectors. They claim that the time to recover will be four years from now. Hence, small business owners must have a plan considering sales, cost of goods, gross profit, labor, occupancy, advertising and promotion, and operating income. All these variables depend on the number of consumers.

## III. Methodology of Model Tacos Food Supply Chain and Food Waste Estimation

Any supply chain is a complex system, and pieces of it or the entire chain can use simulation, considering variables that are subject to be analyzed. For our research, we focused on the food supply chain to create a taco.

We introduce the Ontology concept and Computer Agents to carry out the proposed research and simulation. On one side, computer agents dynamically allow information retrieval, and they are smart software objects used for decision making. They are capable of autonomous actions, sociable, reactive, and proactive in all the environments in which they interact. Also, with some Agents platforms, we can visualize the simulation of processes advancing over time as a tool plots different scenarios for a city. Likewise, ontology recovers knowledge information. It is a way to enrich the context of the knowledge domain, share, and scale the same ontology to similar problems. So, we can explain each knowledge domain and the meaning of data and reuse data for different software systems. The ontology goes hand by hand with the computer agents to locate vital information within the Web, and can understand such information [9].

### A. *Creating the Ontology for Taquerias Supply Chain*

For a first ontology, we need to prototype the attributes for the components analyzed using classes and individuals to simulate the problem of tacos food waste. Figure 6 shows the classes that composed the project: consumers, producers, suppliers, and taquerias. To model the ontology, we use the open-source software Protégé, providing a graphical interface to set up all classes in a standard format. Later, we have to define the properties we use for these classes presented in Figure 7 and enable individuals' creation.


*Figure 6. Ontology classes for the multi-agent system for the tacos food supply chain.*

Later we have to define the properties we use for these classes presented in Figure 7 and enable the creation of individuals.

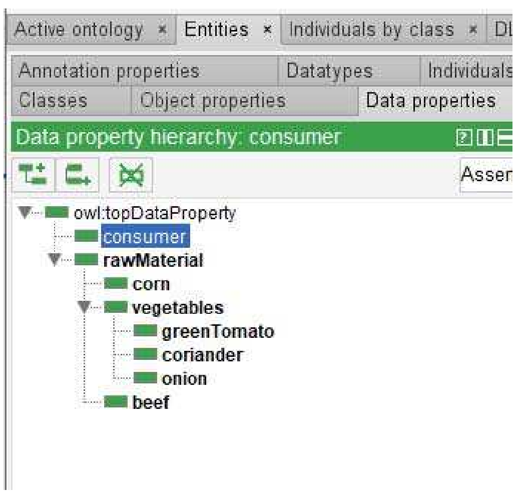



*Figure 7. Ontology properties for each class created on the tacos food supply chain.*

Finally, we have the entities who are the actual instantiation of the class. We implemented four entities to model the agents with an ontology, as shown in Figure 8.

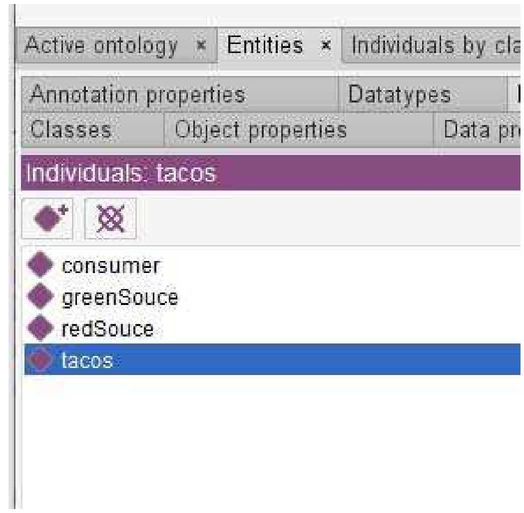



*Figure 8. Entities identified to build the ontology*

```
to save-structure [proyecto]
    owl:domain "tacos" "tacos"
    owl:range "tacos" "tacos"
    owl:domain "taqueria" "taqueria"
    owl:range "taqueria" "taqueria"
    owl:domain "abastos" "abastos"
    owl:range "abastos" "abastos"
    owl:domain "productores" "productores"
    owl:range "productores" "productores"
    owl:domain "persona" "persona"
    owl:range "persona" "persona"
    owl:model "Taqueria.owl"
    owl:structure "proyecto"
end
```

*Figure 9. Ontology in OWL ready to be integrated to the multi-agent platform.*

## IV. Multi-agent simulation and results

### A. *Experimental architecture and design*

Our experiment uses three main components for Multi-agent Platforms: NetLogo, BDI (Beliefs, Desires, and Intentions) architecture and the implementation of Ontology's using Protegé OWL.

We can summarize the technical environment to develop the project as follows:

- 2 Laptops:
  -1 MacBookAir7,2, Operating System: Mac OS X, Processor Type: Dual-Core Intel Core i5, RAM: 8192
  -1 Windows 10, 4 GB RAM Intel(R) Core(TM) i5-8250U CPU @ 1.60GHz, 1800 Mhz, 4 main processors, 8 logic processors HD 1 TB
- NetLogo [10] ver 5

- BDI Architectures as the primary foundation for the creation of computing agents.
- Ontology created on WEB Protégé OWL ver 5.2.0 2017 [11]

For the simulation, we explain our core platforms and approaches briefly:

**NetLogo** [10] is a multi-agent programmable modeling environment" and is our tool to implement BDI architecture and Ontology for our simulation.

**BDI architectures** allow management of a computing agent in a similar way to an artificial intelligence program where beliefs are information that the agent has about the world; Desires are objectives, what the agent wants to achieve, and finally, the intents that we could classify as tasks. It helps to simulate the behavior of taco consumers better.

Last, **ONTOLOGY,** the most common ontology definition, is the following (Gruber 1993). "A body of formally represented knowledge is based on conceptualization. A conceptualization is an abstract, simplified view of the world that we wish to represent for some purpose. Every knowledge base, knowledge-based system, or knowledge-level agent is committed to some conceptualization, explicitly or implicitly. An ontology is an explicit specification of a conceptualization." [12].

## *B. Mathematical model of the simulation*

The model used is a different model for growth according to the following formula:

Model for the supply chain of TACOS Number of Tacos

N = N(t) Number of tacos at time t. (1)

Then the decrease in demand for cues is represented by the differential equation model:

$$N' = r\,N \qquad (2)$$

Where r is the growth rate of the taco population. If $r > 0$ the population will increase in size, if $r < 0$ the population will decrease. At the initial instant t=0, the number of individuals is zero. We have a solution in the form of separable variables in Figure 10.

$$\int \frac{1}{N}\,dN = \int r\,dt$$

$$\ln|N| = rt + C$$

$$N = C\,e^{rt}$$

*Figure 10. Differential function for tacos demand*

## *C. NetLogo multi-agent simulation results*

The idea behind this work is based on a simulation using NetLogo V5 [10], integrating an Ontology.

NetLogo Figure 11, we simulated three small businesses selling "tacos" and reflect the number of consumers to show how many supplies (or components of a taco) we have. When we connect it with the ontology, a class plate instance has a taco with tortilla beef meat, onion, and coriander. This class helps to reflect the impact on the food supply chain. It has an internal formula to calculate the food waste generated for the low sales simulated on the agent's consumer behavior due to COVID-19.

The agent represents the the diner guess~~t~~ for the taqueria, and the places involved to which people will go to consume ~~it~~ is specified in the agent's domain, it is a chain of diners or consumers and producers.

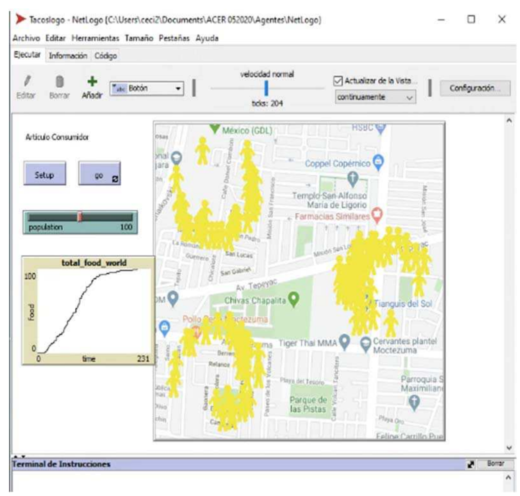
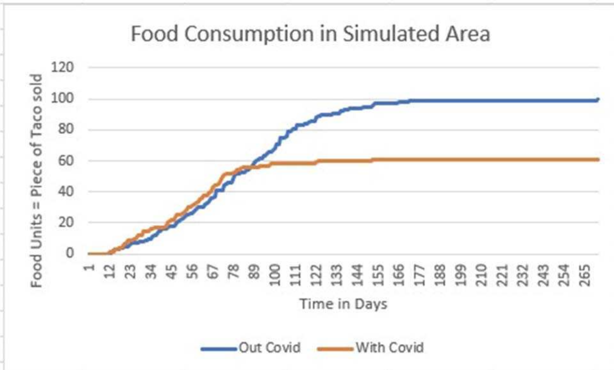



*Figure 11. NetLogo simulation with 100 dinner guests surrounding Taquerias*

As a result of the simulation, we have a sample reducing 40% of sales on a taqueria check Figure 12.



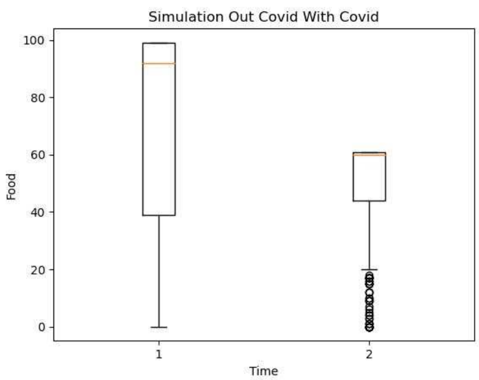




*Figure 12. Simulation in the typical situation of tacos supply chain sales versus situation with COVID-19 with 60% sales*

Figure 13 shows the flow of actions used to integrate agents tasks:

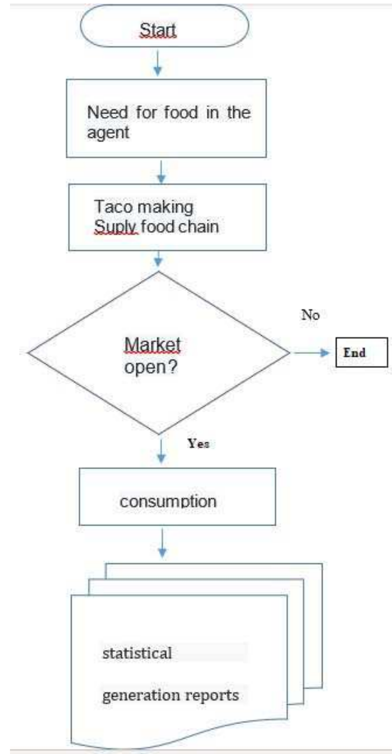



*Figure 13. The flow diagram for the agent's basic processes on the simulation*

## V. CONCLUSION

We see that the social and economic impact of COVID- 19 has marked a milestone in history. The world was not ready to face such a case. The isolation almost wholly stopped the world economy causing damages to the human condition that will slowly recover. Business stopped completely, there were many job losses in various sectors, and the problem was very similar in the food chain. Although we are talking about an essential product such as food, especially the "Taco." We analyze that sales generally decreased by approximately 40%. Businesses need to adapt to the healthy distance and the reduced number of consumers. We have palliative measures such as healthy distance and hope that economic recovery will rise. Our experiment gives us information to work on the following proposals:

1. Prediction on the food supply chain is possible and scalable to any region in the world. Based on simulations, decisions can be made on the government and social organizations (such as chambers) to decrease hybrid and carbon footprint. This simulation considers a ubiquitous product bought in a small area daily; simulation shows the HIGH impact on the

footprint. Future work considers tracking back and checks the agriculture domain. This work is a start point, and it can provide us ways to solve a piece of the food problem and start making changes to the agriculture process. Once a situation like COVID-19 appears, which could be the actions to avoid waste and avoid such an impact on hybrid and carbon footprint.

2. Waste of food can be tracked back and identify processes to avoid waste by donating to a food bank [13]. Impact on small business is not the only piece of the process. We impact the markets, decreasing tons of sales, and track it back to Agriculture. Future work can be to focus on simulation to the different processes on the food supply chain. Instead of wasting food, we could predict which area will have excess and create a Government program to use that food in a different way that is going to waste.
3. Digitalization processes for small business is a must. On a smart city using social communities, we have a significant opportunity to implement an owned platform that will remove 30% of the fee that small business needs to pay to current platforms to sell food. After this article was submitted, the Gastronomy chamber promotes an app to help small businesses sell their food. The fee is 0% license price is considered cheap $140 USD.

Since the multi-agent simulation has a visual interface, the platform helps to understand the different impacts on food waste. As part of future work, we will submit the code into a Github repository for other cities looking to adopt or scale the simulation. However, at the Smart Cities Innovation Center at the University of Guadalajara, we are also looking at the municipality to connect food waste with local economics, mobility, environmental impact, and healthcare. We are working in a digital pilot with the Internet of People (IoP) Jalisco platform as a game-changer where a mobile application will collect data and create incentives with a social coin to keep a balance among other city dimensions in the Supply Chain [15]. This platform can help with scenarios to predict food waste trends, create awareness in the local community, and incentivize behavioral change toward a better place to live and a real smart city.

ACKNOWLEDGMENT

We acknowledge the University of Guadalajara Smart Cities Innovation Center's support and its team for the discussions and vision about the project. We also acknowledge IBM Campus Guadalajara and especially Mr. John Rosato at NY for his support and intensive review of this paper. We also acknowledge the Municipality of Zapopan for its interest in developing a pilot connecting mobility and food and the Jalisco State Government for its support and grant for the IoP Jalisco digital platform.

## REFERENCES

[1] *Food and Agriculture Organization.* http://www.fao.org/home/en/

[2] I. Felix, A. Martin, V. Mehta and C. Mueller July 2020 *US food Supply Chain disruptions and implications from COVID-19.* https://www.mckinsey.com/industries/consumer-packaged-goods/our-insights/us-food-supply-chain-disruptions-and-implications-from-covid-19?cid=other-eml-alt-mip-mck&hlkid=b42b80ea6d21417782897d0021805fa8&hctky=9574140&hdpid=8d1ecfd7-c214-4d3a-82a3-946325aa9d6c#

[3] S. Smit, M. Hirt M, K. Buehler, S. Lund, E. Greenberg and A. Gonvindarajan, March 2020 *Safeguarding our lives and our livelihoods the imperative of our time.* https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/safeguarding-our-lives-and-our-livelihoods-the-imperative-of-our-time .

[4] *"Industria restaurantera de Jalisco desacelera por incertidumbre: CANIRAC"* *https://www.eleconomista.com.mx/estados/Industria-restaurantera-de-Jalisco-desacelera-por-incertidumbre-Canirac--20190611-0127.html*

[5] M. Mata, May 2020 *"Cada vez más critica la situación de los restauranteros por la cuarentena."* Gaceta Universitaria, UDG http://www.gaceta.udg.mx/cada-vez-mas-critica-situacion-de-restauranteros-por-cuarentena/

[6] A. Y. Hoekstra. The water footprint of food. Netherlands: Twente Water Centre.

[7] M. M. Aldaya, A. K. Chapagain, A. Y. Hoekstra, and M. M. Mekonnen, The Water Footprint Assessment Manual. Routledge, 2012.

[8] R. H. Perez-Espejo, R. M. Constantino-Toto, and H. R. Davila-Ibanez, Water, Food and Welfare, vol. 23. Cham: Springer, 2016.

[9] M. Hadzic, Pornpit W. (2009). Ontology-based Multi-Agent System. Poland: Springer. pp 37-59.

[10] NetLogo Simulator. http://www.netlogoweb.org

[11] Protégé- OWL: https://protege.stanford.edu/overview/protege-owl.html

[12] M. Hadzic. Ontology-Based Multi-Agent System, Springer. Poland, 283 pp.

[13] Bank foods in Mexico: https://www.bamx.org.mx/

[14] CANIRAC Gastronomic chamber in Jalisco (Guadalajara is its capital) - Number small business https://canirac-jalisco.com/2019/11/26/todo-sobre-la-mesa-cifras-de-la-industria-restaurantera-para-maximizar-su-potencial-economico/

[15] Internet of People Guadalajara metropolitan area web site https://iopjalisco.org