Meeting Urban Food Needs: Food Supply and Distribution Systems as Complex Systems

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Abstract

The growing of urban population and the fast urbanization process, in developing nations and those in transitions, are both strongly affecting to which extent quality and safe food can be made accessible to urban households. In order to meet urban food needs of urban family units, effective, coordinated and sustainable interventions, framed within local policy, strategy and planning perspectives, are required to increase the efficiency, dynamism, comprehensiveness and sustainability of Food Supply and Distribution Systems (FSDS). This work aims to discuss how a complex-systems perspective can shed light on the analysis of complex FSDS when aiming to meet urban food needs. Firstly, the study explores the common features between complex systems and FSDS and defines the viability of a System Dynamics approach to meet the challenge. Then it proceeds through a qualitative analysis by means of specific tools of the methodology and finally ends up with a quantitative analysis and explores the outcomes of a first set of testing scenarios.

Keywords

System Dynamics, Urban Food Needs, Food Supply and Distribution Systems, Complex Systems, Urbanization Process, Food Security.

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Issue Addressed – Meeting Urban Food Needs

The quick development of urban populations and related food needs, in developing nations and those in transitions, strongly affects the degree to which great quality and safe nourishment can be made accessible to urban family units (Armendariz et al. 2015a).

Therefore, in order to address this issue, effective, coordinated and sustainable interventions, framed within local policy, strategy and planning perspectives, are required to increase the efficiency, dynamism, comprehensiveness and sustainability of Food Supply and Distribution Systems (Aragrande and Argenti, 2001).

FAO (Food and Agriculture Organization of the United Nations) defines Food Supply and Distribution Systems (FSDS) as "complex combination of activities (production, handling, storage, transport, process, package, wholesale, retail, etc.) operated by dynamic agents, enabling cities to meet their food requirements" (Argenti & Aragrande, 2001).

According to the "FAO's methodological and operational guide to study and understand *Food Supply and Distribution Systems (FSDS)* to cities in developing countries and countries in transition" (Aragrande and Argenti, 2001) - in the context of this paper, we will refer to it as **FAO's Guide** for brevity - a food supply and distribution system (FSDS) is principally divided in two main subsystems (see Figure 1): food supply to cities, and food distribution inside the urban area. Each subsystem is concerned with different activities that form the overall system (Armendariz et al. 2015a).

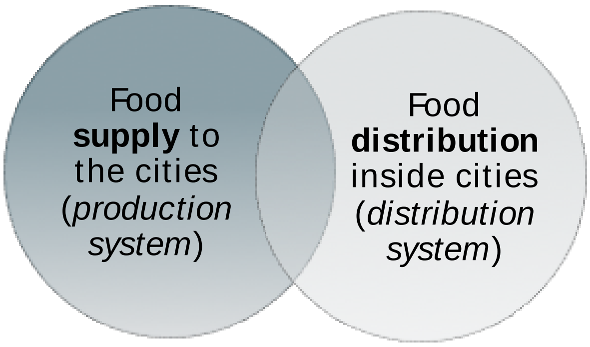

Figure 1 - FSDS sub-systems (Armendariz et al. 2015a)

What should be the policy to *meet urban food needs* in developing countries and those in transition? According to Armendariz et al. (2015c), that is the primary question posed into the FAO's Guide (Aragrande and Argenti, 2001), to face the current uncontrollable increase of urban population and the growing urbanization pressures on food systems.

In order to answer the question, the preliminary phase of our study aims to discuss *how a complex-systems perspective can shed light on the analysis of complex food-systems meeting urban food needs*, through the following steps:

- ✓ (Step - 1) Exploring the common features between complex systems and Food Supply and Distribution Systems (FSDS)

- ✓ (Step - 2) Developing a brief review of the major approaches - agent-based models (ABM), social network analysis (SNA), and system dynamics (SD) - in order to make an assessment on the analysis performance of different complex system methodologies while dealing with FSDS.
- ✓ (Step - 3) After shifting out the most suitable methodology for the study of FSDS, Step 3 aims to elicit a system archetype analysis of the FSDS dynamics from the methodological guide of FAO.

The findings of the preliminary phase are inputs to a further phase of study. Therefore, the objective of this further phase is to improve the FSDS understanding, as complex systems embedded in socio-ecological contexts. A framework setting to understand the FSDS structure and its dynamics is presented and described as a CLD diagram (Step – 4); and summed up by means of a Bubble Diagram (Step -5). Finally, a quantitative model (Step – 6) has been developed and a set of scenarios have been simulated.

The study conducted so far and its further developments will aim to contribute as an update to FAO's Guide, Aragrande and Argenti (2001).

First Step - Food Supply and Distribution Systems (FSDS) as Complex Systems

In the last 50 years, a few worldwide associations utilizing distinctive methodological methodologies have anticipated the growing of world's population and predicted therefore, food demand increase for the next decades.

Armendariz et al. (2015a) states that: "An integrated assessment of changing technical, economical, social and environmental factors affecting both the urban and the rural areas is calling not just for the use of new tools, which are capable of making the evaluation of dynamic elements interacting among them, but also for a new comprehension capable of revealing a systemic approach coherent with real world FSDS".

The first step of our study, aims to demonstrate to which extent FSDS can be treated as complex systems. The study show FSDS presenting characteristics such as: entirety, feedback, non-linearity, time perspective, counterintuitive nature and self-organization and adaptation capacities (Armendariz et al. 2015a).

As a main consequence of the formal consideration of food systems as complex systems, it emerges the possibility of expanding the use of complex system methodologies to analyse, comprehend, simulate and manage particular aspects of food systems or manage them overall by integrating the use of different techniques.

For all these reasons, complex system methodologies applied to the analysis of FSDS can bring new perspectives to understand and administrate them more efficiently.

Second Step – Comparative Assessment on Complex System Methodologies performance in the analysis of FSDS

The second step aims to operate a comparative analysis of different approaches useful in understanding complex food systems (the analysis is summarized in Table 1) through a qualitative comparison between Agent Based Modelling (ABM), Social Network Analysis (SNA) and SD methodologies performance.

As a result, the comparison showed that System dynamics emerges as methodology among the others, for its ability to address, in an integrated way, diverse levels of aspects of FSDS and broader scope of its application.

Since on the one hand, SD formally is a methodology for the study of the relationship between structure and behavior of systems, to identify high leverage points to successfully manage the system, to test (by applying them in a virtual environment) possible policies and to forecast the results of policies in the long-term through simulation (Sterman, 2001). On the other hand, its limitations are on addressing emergent behavior, assessment of individual dynamics of agents or actors, a proper and detailed spatial-geographic assessment (Armendariz et al 2015a).

Furthermore, it is worth reporting that precedent SD applications on the analysis of Food Systems consider SD models more appropriate for policy evaluation, because of their capability to provide an assessment of long-term effects and a deep understanding of the causality among variables.

Table 1 - Assessment on Complex System Methodologies performance in the analysis of FSDS (Source: Armendariz et al 2015a).

Complex Systems features	Agent Based Modeling	Social Network Analysis	System Dynamics
Entirety	Medium	Low	High
Emergence	High	Low	Medium
Interrelations	Medium	Medium	High
Non-linearity	High	Low	High
Feedbacks	Medium	Low	High
Self-organization	High	Low	High
Adaptation	High	Low	Medium
Counter-intuitive nature	High	Medium	High
Time perspective	High	Low	High
Hierarchical organization	Medium	Low	High

General Assessment of the methodology	- Focus on emergent processes and adaptation - Bottom-up analysis - Attention to independence and heterogeneity of agents - Sensitive to initial conditions - Too difficult to analyze several combinations of attributes of agents	- Focus on relational data - Descriptive approach - No consideration of attributes of nodes in a complex system	- Focus on behavior of a complex system over time - Top-down analysis - Descriptive and normative analysis - Possibility of exclusion of important factors affecting the system (subjective bias in the choice of the appropriate model parts) - SD models cannot address spontaneous changes by agents in the system that might constitute an emergent behavior.
Possible applications	- Assess different policies - Understand the emergence of coalitions, local initiatives in FSDS	- Descriptive analysis of intensity, strength or absence of connection among the elements of a FSDS - Analysis of the main hubs of a food system in order to understand possible areas of intervention	- Simulation and analysis of the impact of different policies and interventions in order to increase the efficiency of a FSDS - Qualitative and quantitative analysis of performance of a FSDS

Third Step - System Archetype Analysis of the FSDS dynamics (Analysis of the FSDS Dynamics using System Archetypes)

The third step aims to show a general analysis of the main dynamics of FSDS, through a system archetype analysis.

The CLD showed in Figure 2, allows to observe four main loops and to identify: a “Drifting Goal” archetype, in which B1 and B2 indicate the main balancing loop; a “Shifting the Burden” archetype, where R3 indicates the effect of a reinforcing loop; and finally R4 indicates a possible “Fixes that fails” archetypes associated with reductionist focus of food policies. In case of policies, which tend to raise production and industrial processing - without take into account benchmarks of social metabolism and sustainability of natural resources - a supplemental R4 can be drawn.

All in all, this analysis demonstrates how the balancing loops act in a way that the entire framework tends to a poor development and the policies applied, for this situation fabricating more streets, comes up short as arrangement due the structure of the framework and distract from the important issues to deal necessarily with (Armendariz et al 2015a).

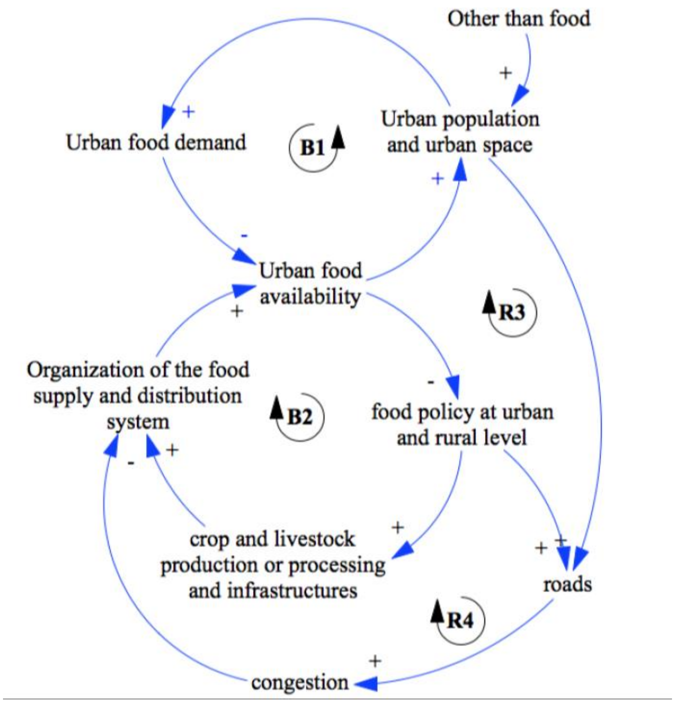

Figure 2 - System archetypes applied to food supply and distribution system (Armendariz et al 2015a)

Basic points (Armendariz et al 2015a), elicited from a preliminary application of system archetypes analysis to FSDS are:

(1) The functioning of the FSDS are embedded in the field of Urban Dynamics.
(2) Population growth as the main problem to feed cities because it raises the food demand, is partial, thus, is wrong.
(3) The system has to be studied in an integrated way for the achievements of effective policies.
(4) Urban and rural dynamics cannot be longer treated in isolation if integral solutions or better policies are looked.

Fourth Step - FSDS Qualitative Model: Elaboration of a CLD based on the FAO's Guide

The fourth step aims to study critically the FAO narrative based on Aragrande and Argenti (1999). FAO's Guide (Aragrande and Argenti, 1999) consists in a seminal study for the characterization of food supply and distribution systems based on the developing countries and countries in transition observation, especially from Latin America, Africa, Near East and Asia.

After a first process of classification of FAO variables in stock, flows, endogenous and exogenous variables, an elaboration of an extended CLD based on FAO variables aimed to consider all processes focused by the FAO methodological guide has been carried out.

Such an identification of main stocks and dynamics of FSDS according to FAO has been conceptualized in a CLD (Armendariz et al 2015b). The FSDS CLD Figure 3 shows complete image of the work done: it has been identified and categorized the main FSDS variables, conceptualized the FSDS, and finally characterized and analyzed their dynamics.

Among the analyzed dynamics, it has been highlighted how the traditional logic to build policies is erroneous: in fact, decreasing the resilience and efficiency of the system, impacts on the possibility of reaching the goal "meeting urban food needs" (Armendariz et al 2015b).

Fifth Step - FSDS Bubble Diagram (Framework Setting) based on the FAO's guide

This further step provides the elaboration of a summarized diagram to better focus the main dynamics of the FAO perspective and framework.

After a primary analytical step of a CLD conceptualization and description, the fifth step develops a framework setting that explains at an abstract level the dynamics between land, population, distribution and production process, resources, technology and job dynamics.

Starting from the CLD elicited from the FAO's literature we have selected the main modules that allow us to conceptualize in a simple way the environment and complexity of FSDS and we framed them in a so-called Bubble Diagram.

This work aims to enhance the communication of a systemic and dynamic perspective of FSDS among different recipients, especially decision makers of developing and transition countries under FAO's guidance, and is expected to boost theoretical and practical discussions in the area.

One fundamental insight of this phase (Armendariz et al 2015b) was that increasing the efficiency of the food production and distribution (production, assembling, handling, processing, packaging, transport, storage, wholesaling and retailing) could lead to increase the food supply to cities, reducing costs and waste.

But, it does not imply automatically meeting the food requirement per capita. Socioeconomic conditions as: the prevalence of poverty –topic considered in the goal but absent of FAO's policies-, ecological conditions as the availability of resources and land or urban conditions as the urban space and infrastructure will get the system working in misbalance with its capacity.

In this sense, we want to stress that as production and distribution processes will have to be improved, other big issues of the system we inhabit will be have to acknowledge. It is irrelevant to analyze FSDS without considering the important stocks that make them possible. The task now is to find the scenarios of the system viability and feasibility over the next years targeting to the goal.

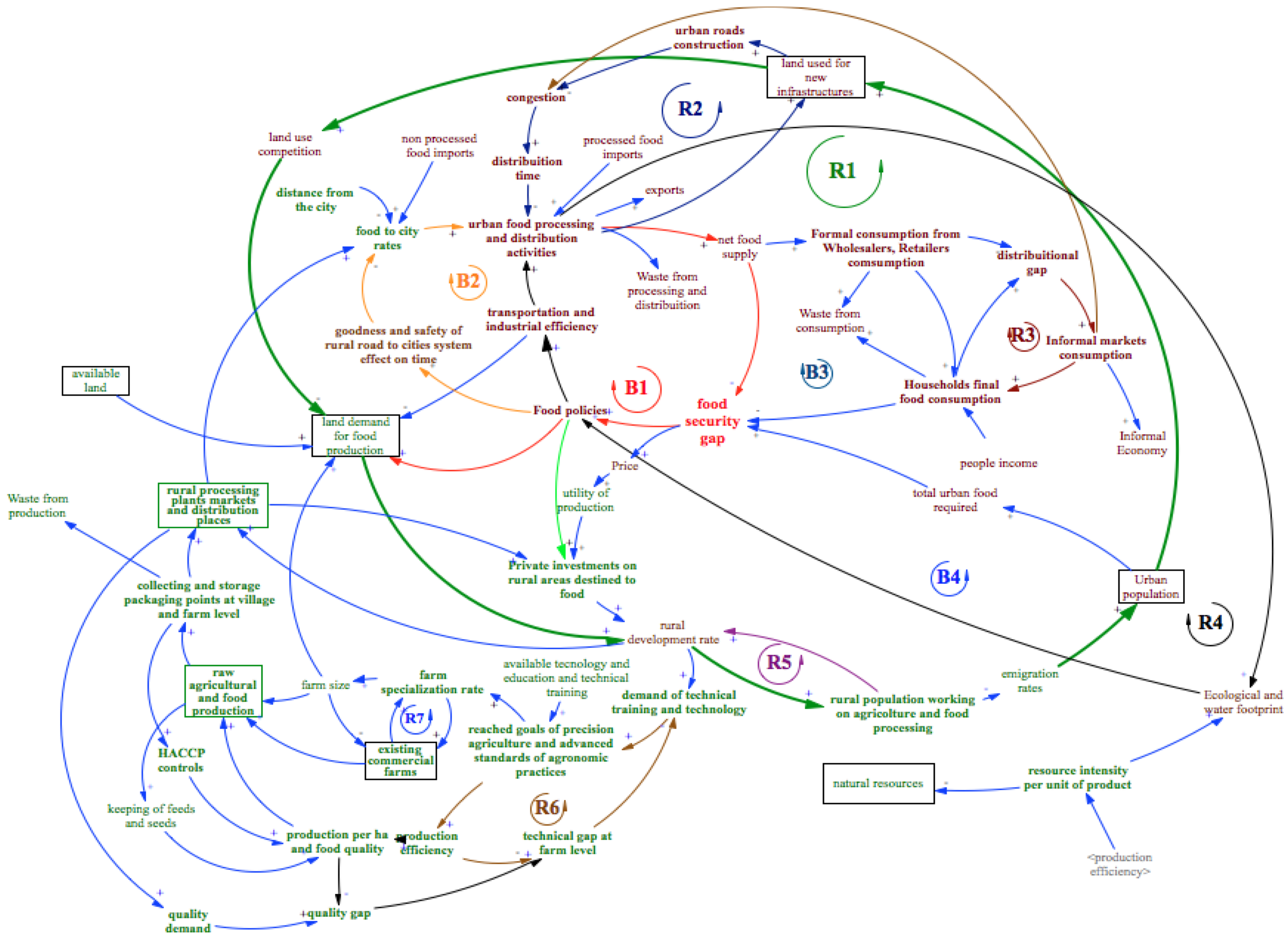

Figure 3 - Qualitative analysis of FSDS dynamics required by FAO as an introduction to SD methodology. Based on Aragrande and Argenti, 1999. (Armendariz et al. 2015B)

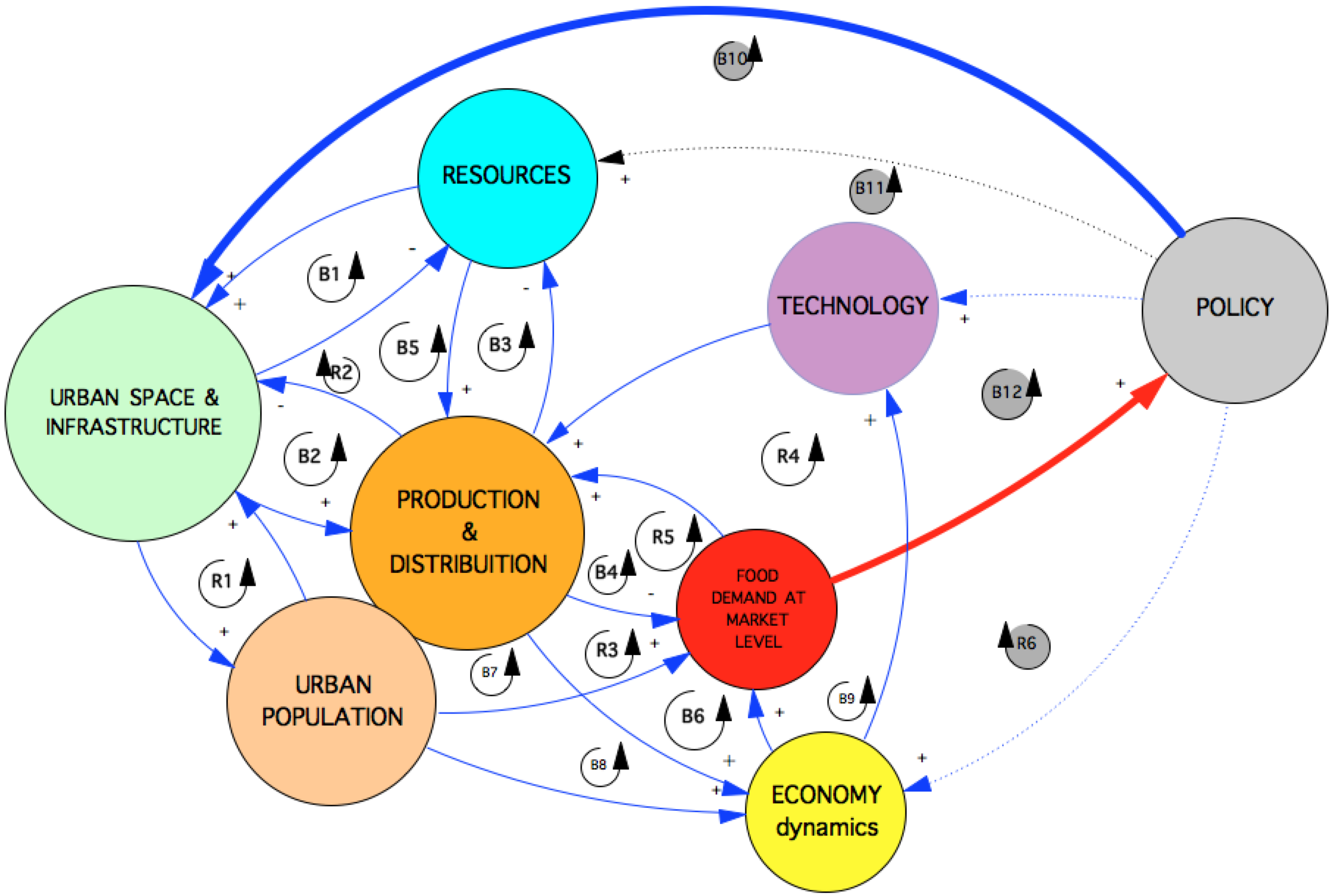

Figure 4 - Framework setting of FSDS. (ARMENDARIZ ET AL. 2015B)

Sixth Step - FSDS Quantitative Model

Conceptualization of Variables and Stock & Flow Diagram

Having analyzed the problem through a Casual Loop Diagram of both the system components and the causal relationships between the different parties, having tried, then, to establish feedback loops and to recognize any systemic archetypes, the research was focused on the construction of the Stock and Flow Diagram, making use of the characteristic blocks of modeling methodology in order to describe the connections between the variables of the model, identified through the causal maps.

A good SFD is able to show in advance the evolution of all variables considered in the CLD, so as to guarantee the possibility of an intervention from the outside in case of necessity.

As a starting point for the construction of the SFD, it has been chosen a CLD (see Armendariz et al 2015b) built on the research work of Aragrande and Argenti (1999) and validated by FAO .

First, it was necessary to define the system boundaries and the details to be included (level of accuracy of the model); then, the final SFD was built by using the software Powersim, a fundamental step in understanding how the most important variable of this work - the Food Security Gap - is strongly affected by both the individual and global behavior of the other variables in the system.

Some feedback loops of the starting CLD, have been modified and/or expanded, in order to make the final model as complete as possible, and to obtain, consequently, the most valid results during the simulation.

One of the biggest problems in building the SFD was certainly the aspect of the policies, as in the starting CLD the entire, large set of possible investments had been represented by a single variable. As considered this a limitative approach for the paper, the variable was upgraded and differentiated into seven different subgroups of policies, divided by sector impact (highlighted in red in the SFD).

A very important variable in the final model, second only to the Food Security Gap, is that of the ecological footprint: a very complex indicator used to evaluate the consumption of natural resources compared to the ability of the land to regenerate them. It measures the biologically productive area of land and sea needed to regenerate the resources consumed by a human population and to absorb waste products.

Since it was not possible to retrieve the data required for the calculation of this index, for this research it has been decided to use an alternative calculation method developed in the literature, less precise but still valid; it relates the amount of produced waste, the consumption of resources and the ability to regenerate them with the totality of the population of the selected context.

A region of the SFD has been devoted to the construction of the variables related to the distribution time of the imported food. But, as can be seen, these variables have been disconnected from the rest of the model since it has been chosen as the time of simulation a T = 30 years and a dT = 1 year: since the distribution time variable was of the order of 20 -25 days, it would not have influenced the behavior of the variables of interest.

The purpose of this paper is to demonstrate how an SD approach is an excellent methodology to deal with food security and distribution systems' problems; for this reason, it was decided not to use real data from a specific city, but to consider estimated data, in order to avoid the risk of neglecting some variable and to understand how this model can be adapted to every situation.

The initial hypothesis from which the model started was to monitoring the system's behavior of a generic town of South America of 500.000 inhabitants. From this, by consulting specific websites such as FAO or statistical websites, it was possible to assign initial values to the relative levels and find the relationship between the variables considered in the model.

Simulation and first set of testing Scenarios

Originally, the case BAU (Business as usual) -the departure scenario in which there was no application of any kind of policy- was simulated; thanks to this original setting, it was possible to understand how both variables –Food security gap and Ecological footprint- adopt an upward trend over time, worsening even more the departure situation.

Consequently to this results the research was developed proposing and simulating three different scenarios, each of them including the application of different policies to demonstrate the validity of the SFD model and to show how each policy have a different impact on the behavior of the model's variables. The first scenario included the application of rural context policies, the second one involved the citizens context policies, while the third one concerned the activation of all the policies but, of course, lower investments.

A common hypothesis to all three scenarios, concerning the application of the policy for the rural population's development, aimed to counter the emigration's rate of the rural population working on agriculture and food chains, from rural areas to cities.

Since it would be unrealistic thinking that the effects of applying a policy could be immediate, it was included in the simulation a delay function that allowed to dilute the positive effects of an investment over time.

The scenarios were simulated looking for (and finding) the minimum values of the investments that would be able to reverse the trend of the Food Security Gap variable; the same approach was adopted relatively to the Ecological Footprint variable. After that, these three scenarios were simulated again with values slightly higher than the minimum investments found previously, to show how even small, positive changes of the management tools can generate significant, positive effects both in terms of time and quantity.

The results of this model show that the early understanding of the dynamics of cause and effect between the variables can help in identifying the management tools of greatest impact for any context being examined, and in acting on them. However, this model can not guarantee highly accurate results in numerical terms for several reasons: firstly each town, each region will have its own urban dynamics and especially its investment budget limits; secondly and most importantly, the model does not analyze 'hidden issues' definitely present in developing countries, as the rate of corruption, illegal employment and the exploitation of the population.

Concluding, the final proposed model can be used as the basis for any future developments, perhaps expanding the boundaries chosen in this discussion or developing even more every single variable; mainly because the model was made on the basis of a CLD validated by FAO - and, coherently to the System Dynamics, the structure of the model determines its behavior - it can be considered a valid and accurate decision making tool.

Conclusions and Further Steps

As main consequence of this study, it emerges the possibility of using complex system methodologies to analyze, comprehend, simulate and manage particular aspects of food systems. Particularly, it has been demonstrated that Food Supply and Distribution Systems (FSDS) can be treated as Complex Systems; it implies that the applicability of complex systems methodologies can bring a new perspective to understand and manage them more efficiently.

After a comparative assessment between complex systems methodologies, this study showed that System dynamics emerges as methodology among the others, for its ability to address, in an integrated way, diverse levels of aspects of FSDS and broader scope of its application.

The application of a System Archetypes Analysis to the study of FSDS, showed that the functioning of the FSDS are embedded in the field of Urban Dynamics. Moreover, population growth as the main problem to feed cities because it raises the food demand, is partial, thus, is wrong. Finally, the system has to be studied in an integrated way for the achievements of effective policies and next, urban and rural dynamics cannot be longer treated in isolation if integral solutions or better policies are looked.

The identification of main dynamics of FSDS, it has been highlighted how the traditional logic to build policies is erroneous: in fact, decreasing the resilience and efficiency of the system, impacts on the possibility of reaching the goal “meeting urban food needs”.

One fundamental insights of the qualitative analysis was that increasing the efficiency of the food production and distribution could lead to increase the food supply to cities, reducing costs and waste. But, it does not imply automatically meeting the food requirement per capita. In this sense, we want to stress that as production and distribution processes will have to be improved, other big issues of the system we inhabit will be have to acknowledge.

Concluding, the final proposed model can be used as the basis for any future developments, surely expanding the boundaries chosen in this discussion and developing deeper a set of characteristic variables. The simulation outcomes proved that the early understanding of the dynamics of cause and effect between the variables can help in identifying the management tools of greatest impact for any context being examined, and in acting on them.

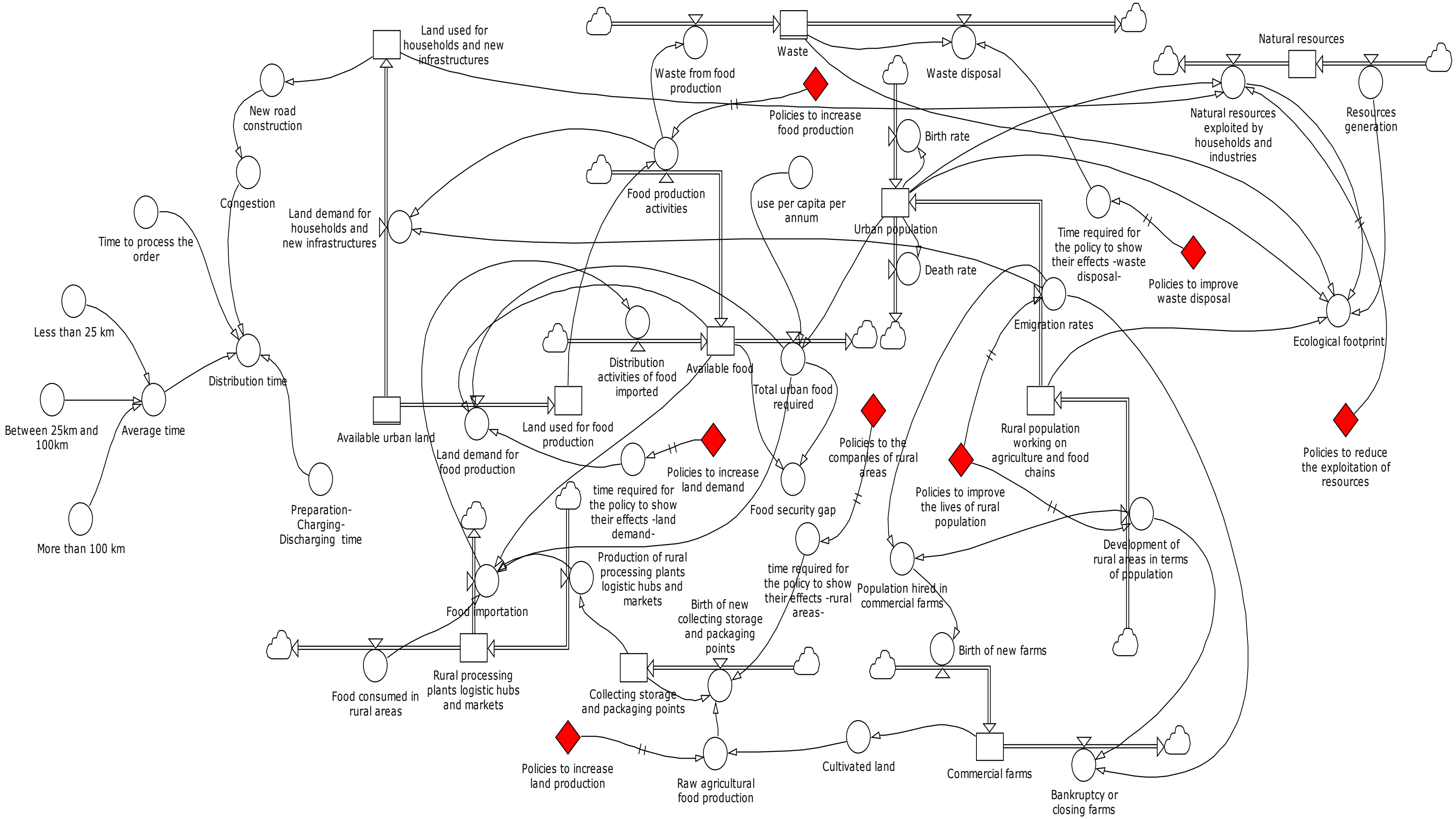

Figure 5 - Stock and Flow diagram built with Powersim software - Own Elaboration

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