THE 5TH INTERNATIONAL WORKSHOP ON SIMULATION FOR ENERGY, SUSTAINABLE DEVELOPMENT & ENVIRONMENT

SEPTEMBER 18 – 20, 2017

BARCELONA, SPAIN

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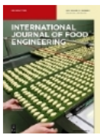

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CHAIRS' MESSAGE

WELCOME TO SESDE 2017!

It is a great pleasure and honor to welcome you in Barcelona (Spain) for the International Workshop on Simulation for Energy, Sustainable Development & Environment (SESDE 2017).

Building on the success of previous SESDE editions, the topics SESDE 2017 is focused on investigate the application of Modeling & Simulation theories and methodologies on the concepts of Energy, Sustainability and Environment. Over the last decades, the concept of sustainability has evolved rapidly and in an integrated way. Social and environmental aspects could not be neglected anymore and have been gradually embedded into a wider framework. The SESDE workshop aims at embracing this evolution and thanks to gifted researchers, academics and professionals the workshop proposes very high-quality papers (also thanks to the invaluable work of the IPC). This year topics include the analysis of urban land-use development and the use of new emission free vehicles in urban logistics networks, sustainability evaluations in retail stores, the analysis through LCA of food-related products, the use of autonomous systems in industrial plants and the analysis of decision support systems for disasters prevention in urban areas. The multidisciplinary framework where SESDE is co-located (the I3M Multi-conference) gives the opportunity to the participants to have a wider mind-set and receive sparks for new research ideas from different domains.

Therefore as General and Program Chairs, we also intend to thank the I3M organizers, the IPC and the local organization that give us the opportunity to enjoy the wonderful scenario of Barcelona. We are sure that, sharing ideas and opening new collaboration paths among the participants of this workshop, will boost the state of the art and push the world towards a bright future.

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AGENT-BASED MODELING OF URBAN LAND-USE DEVELOPMENT: MODELLING AND SIMULATING HOUSEHOLDS AND ECONOMIC ACTIVITIES LOCATION CHOICE IN BORDEAUX, FRANCE

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ABSTRACT
This article aims to respond to growing concerns about sustainable urbanization, which in recent years have generated a need for prospective assessment in the field of transport and land-use planning, by predicting future land-use development. We introduce a Land Use model (part LU of a Land Use Transport Interaction model) which aims to simulate households and firms location choice within an urban system. We use the agent-based approach to simulate location choices in order to account for land use changes and to estimate residential and economic activities location. This is a dynamic bottom-up approach with the households and the firms as their basic components. The MUST-B model considers the agents' location choices according to the utility theory and the equilibrium between real estate supply and demand. The model is used to simulate urban land-use development in the urban area of Bordeaux, France.

Keywords: Land use, agent-based modeling, location choice, accessibility, decision support system.

1. INTRODUCTION AND OBJECTIVES

Sustainable urbanization is a challenging issue in developing countries. The changes that occur in land-use due to urbanization enable a complex process caused by the interaction between natural and social systems (Valbuena, Verburg et al. 2008, Hosseinali, Alesheikh et al. 2013). Increases in population as well as the movement of people from rural to urban areas are the two major factors for this phenomenon. Major economic and social activities take place in the urban areas where complex systems (ex. Land use, transportation, utilities, etc.) interact with each other. The unplanned urbanization has been creating problems like land scarcity and pressure, pollution, traffic, and congestion. To understand and analyze the complexity of urban systems, models of land use and transport interaction serve as important tools for policy analysis and decision support.

Numerous studies show that the limits of daily travel are further extended (Orfeuil 2000). The population in urban areas has grown steadily, now estimated at around 75% in Europe and 80% in France. Many residents of metropolitan regions work within the central urban area, and choose to live in satellite communities commuting to work via automobile or public transport. The process of suburbanization is driven by effectiveness of means of transport, infrastructure, systems, facilities and vehicles. Urban sprawl is causing an explosion in commuting, home-work trips, resulting in increasing congestion of transport infrastructure, pollution at peak times, and dependence on cars (Newman and Kenworthy 1999). In this perspective, many authors ask questions about the fragility of populations living in peri-urban areas and whose transport budget is sensitive to changes in the cost of energy (Crozet and Joly 2004). The scarcity of space, energy and time makes it necessary to understand the residential relocations and the daily movements of households, the commuting conditions of travel and the urban planning. Controlling the phenomenon of urban growth clearly becomes a demand for sustainable development, urban planning and public policies.

Simulation is tremendous opportunity to analyze problems .It provides users with practical feedback when planning real-world systems (Zhang, Ban et al. 2011). It allows planners to study a problem at different levels of abstraction. In the last decade, several land use models have been developed and used to simulate and predict land use change in the future. Without using models that embrace the complexity of the urban system, it would be difficult to simulate and predict the future of urban growth (Hosseinali, Alesheikh et al. 2013). Theories on the interaction between urban land use and transport address the locational and mobility responses of private actors (households, firms and regional commuters) to changes in the urban land use and transport system at the urban-regional level (Wegener 2004). A general framework to model households and firms location choice and their interactions with other parts of the urban system can be framed in three interrelated stages, corresponding to urban development or land-use, activity, and transportation system performance.

There are many modeling tools in use according to different research objectives: the relevant LULI models can be divided into three categories. Firstly are empirical-statistical models. These models are based on data, statistical and econometric analysis to identify the factors of Land Use change (Bin and Tao 2010). Secondly are spatially explicit models, such as the cellular automata model (Ahmed and Ahmed 2012, Han, Yang et al. 2015). Thirdly, agent-based models have been developed to simulate LULI change by individual agents (Parker, Manson et al. 2003). ABMs use the actors of land-use change (individual or institutions) as objects of analysis and simulations, and pay explicit attention to interactions among these 'agents'. Specific advantages of agent-based models include their ability to model individual decision-making entities and their interactions. In this paper, we use the agent-based approach to study urban dynamics and to simulate the households and firms location choices. Our approach aims at integrating land-use factors into an agent-based model for modeling the part LU of a LUTI model: Land-Use changes as an interaction between households and firms location.

To achieve this goal, we will first explain the criteria for selection of a target location for households and firms. Then, we will show how the notion of territorial accessibility affects the real estate market of the Bordeaux region. We will also describe the characteristics and identify the primary driving factors of land use change patterns. Finally, we will simulate the Households and firms location choice in Bordeaux region under different scenarios.

2. BIBLIOGRAPHIC REVIEW

2.1. LUTI Models

The ideas behind residential location modelling have a long history. Residential location modelling dates back to the work of Alonso (Alonso 1960, Alonso 1964) who laid the foundations for the economic analysis by applying Von Thunen's key "bid rent" idea to residential location; and to Lowry (Lowry 1964) who used spatial interaction principles in his Model of Metropolis (Pagliara and Wilson 2010). The basic assumption of the Alonso model is that firms and households choose that location at which their bid rent, i.e. the land price they are willing to pay, equals the asking rent of the landlord, so that the land market is in equilibrium (Wegener 2004). According to Wegener all models rely on random utility or discrete choice theory to explain and forecast the behavior of actors such as households or firms (Wegener 2004). The random utility maximization-based framework assumes that the ultimate goal of an agent's (household or firm) behavior is to maximize its utility. Agents maximize their utilities by choosing a vector of goods and a residential location, described by a set of attributes. Segal (Segal 1977) identified five major characteristics used to evaluate the attractiveness of a residential location: the physical characteristics of the area, its socio-economic characteristics, the public services, the environmental qualities and the accessibility of the area.

LUTI-models combine a Land-Use model with a Transport model. This connection is based on the mutual influence of Land-Use and Transport (Wegener 2004). They have moved from special interaction models or statistical models through econometric models to micro-simulation, cellular automata and agent-based models. Researchers have built several residential mobility microsimulation models and applied them to the context of different countries and regions. Some of the most advanced LUTI models are IRPUD (Wegener 2011), DELTA (Simmonds 2001), MEPLAN (Echenique, Flowerdew et al. 1990), Urbansim (Waddell 2002), MUSSA (Martinez 1996) and MARS (Pfaffenbichler, Emberger et al. 2010). More recent developments have seen a move towards more detail with micro-simulation or agent-based models such as ILUTE (Miller and Salvini 2001). For a good overview of the models and their history, the reader is referred to Acheampong and Silva (Acheampong and Silva 2015), who discuss the existing operational LUTI modeling frameworks as well as the modeling methodologies that have been applied over the years.

The MUST-B Model, presented in this paper, is the part LU of a LUTI model. It introduces a land use model that allows the integration of urbanization and planning mechanisms in terms of the location of households and economic activities. It aims at interacting with a transport model that seeks to take account of the daily mobility. While some LUTI models have been built at an aggregate level, the MUST-B model has gone down the route of using more detailed models. The aim was to make the model easy to use while being easily understood by decision makers rather than black box by involving researchers and consultants in a multi-disciplinary approach in order to identify the interdependencies in the mechanisms that are reproduced by the simulation. Another feature of the MUST-B model is that it can assess environmental consequences of energy consumption and air pollution (e.g. greenhouse gas emission and air quality) related to the mobility and to the building. It aims to integrate the systemic articulation of the land and real estate markets which makes it possible to take into account all the interactions between the different urban actors. Also, MUST-B model integrates the social housing, which accounts for 25% of the national housing stock.

2.2. Agent-based modeling and simulation

The agent based models approach has recently emerged and gained popularity in the urban-related scientific community. It offers a way of replacing transition probabilities at one level with decision rules on entities at lower level. These models use the actors of land-use change (individual or institutions) as objects of analysis and simulations, and pay explicit attention to interactions among these ''agents" (Hosseinali, Alesheikh et al. 2013). Agent based modeling offers various types of agents, models of their behavior and characteristics, through a range of architectures and components libraries. ABM as a modeling technique allows for a natural description of a complex system in a flexible and robust manner so as to capture emergent phenomenon (Silva 2011, Acheampong and Silva 2015). While the use of behavioral rules is similar to other disaggregate simulation techniques, ABM approach allows the agents (e.g., household, firms) to learn, modify, and improve their interactions with their environment (Acheampong and Silva 2015). Several characteristics define agents: they are autonomous, they share an environment through agent communication and interaction, and they make decisions that tie their behavior to the environment so that they shape and are influenced by their environment. Agents make inductive and evolving choices that move them toward achieving goals (Parker, Manson et al. 2003, Wooldridge 2009). The agent-based simulation simulates the effect of changes in policy on each of these micro units. Differences before and after the changes can be analyzed at the micro-level; and aggregated to show the overall effect of the changes (Mitton, Sutherland et al. 2000).

3. DESCRIPTION OF MUST-B LAN USE MODEL

3.1. General Structure

The main purpose of the MUST-B model is to estimate variations in the location of population and jobs, and real estate prices in an urban system to changes that are mainly associated to the transport system (we also envisage to estimate the energy consumption and the level of greenhouse gases GHG emissions). At the end, our objective is to develop an integrated land use / transport model to simulate and evaluate the impact of exogenously given transport and multi-sectoral urban policies such as the implementation of new transport systems or new travel demand management policies and changes in public transport provision. This allows for any change occurring in the territorial system to lead to a new equilibrium solution representing the new state of the system. At the equilibrium of the two models (land use-transport) in interaction, one deduces the energy consumption and the GHG emissions linked to the four sectors: daily mobility, operation of building, urban services and economic activities. Figure 1 illustrates the conceptual structure of the MUST-B Model.

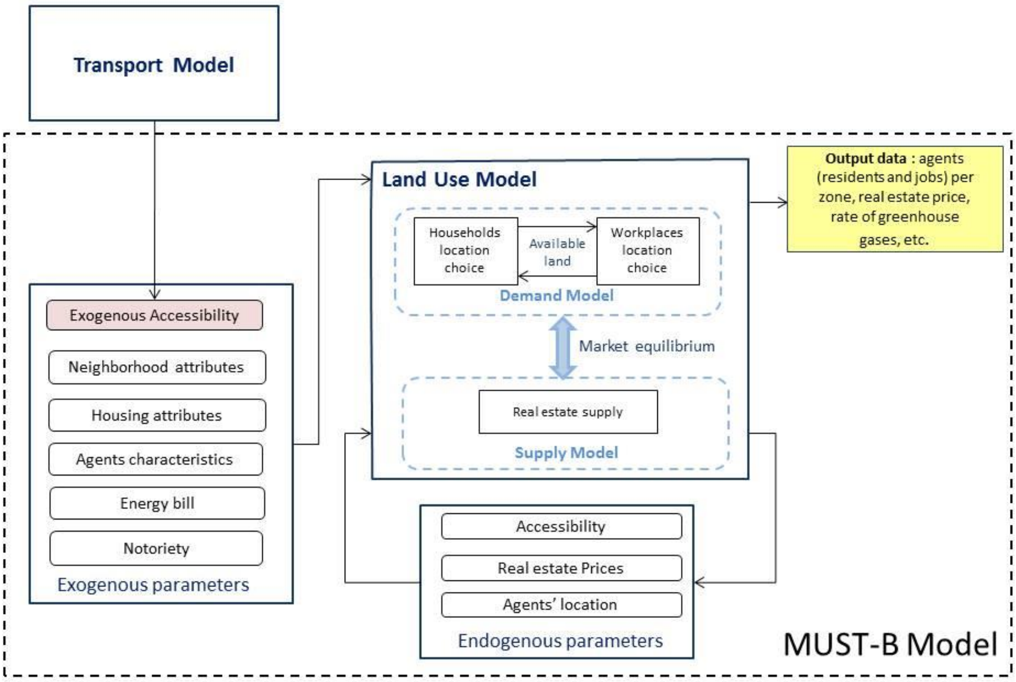

Figure 1: General structure of the MUST-B model

The two sub-models making up the main structure of the MUST-B model are as follows:

- A residential location model that, given a set of real estate prices, and a residential supply, simulates the location of households, disaggregated by income classes, in the study area. It calculates the number of households locating or leaving an area. This model depends on the accessibility to jobs, the capacity and the development model of each zone and the rent in each zone.
- A firm location model that is modeled similarly to the residential location model by differentiating activities according to their spatial footprint. It simulates the distribution of these economic activities disaggregated by an economic sector.

At this stage, we assume that some of the accessibility is exogenous. It is calculated at the beginning by the transport model depending on the available transport supply (network capacity and public transport services), that generates a cost matrix between the zones (expressed in either journey times or generalized transport costs) that, in turn, influence the accessibility of each zone. A transport model that, given a travel pattern (Accessibility) for households and activities, simulates the simultaneous equilibrium between supply and demand in the transport system. Accessibilities are generated based on population, the number of jobs, travel time and travel cost.

The implicit prices model calculates the average real estate prices in each zone as a function of the supply and demand for locating in each zone as well as the structural and environmental characteristics of the area.

The residential location model starts from the hypothesis that households locate depending on different zonal characteristics, including the distance from workplaces, the notoriety or quality of the neighborhood (availability of public services, shopping centers, schools, etc.), or the costs involved including price, taxes, energy load, and travel costs obtained from the interaction between the transport and economic activities location sub-models. Another important variable involved in residential location are the real estate prices of each zone, obtained using the bid function which depends on household utilities. The activity location model works in a similar way to the residential location model, considering the utility of each zone as a function of different variables. Among these variables is the accessibility of the population to each zone, depending on the travel costs between areas derived from the transport model and the population of each zone derived from the residential location model. The simplified flow diagram of the sub-models can be seen in Figure 2. Initially, agents (households and firms) are distributed arbitrarily on the agglomeration respecting the capacity constraint of the areas. We randomly choose an agent *a* candidate to move located in the zone *i*, and a zone of destination *j*.

3.2. Characteristics of the bid function

The allocation of agents to the different zones is based on a bidding mechanism for the acquisition of household or a commercial establishment (firm). The bid function (Equation 1) is derived from the utility function and can be understood as profit in monetary terms. It represents the monetary value that a consumer allocates to the set of attributes of a property, constructed based on a structure of consumer preferences, as well as agent restrictions (such as income in the case of households).

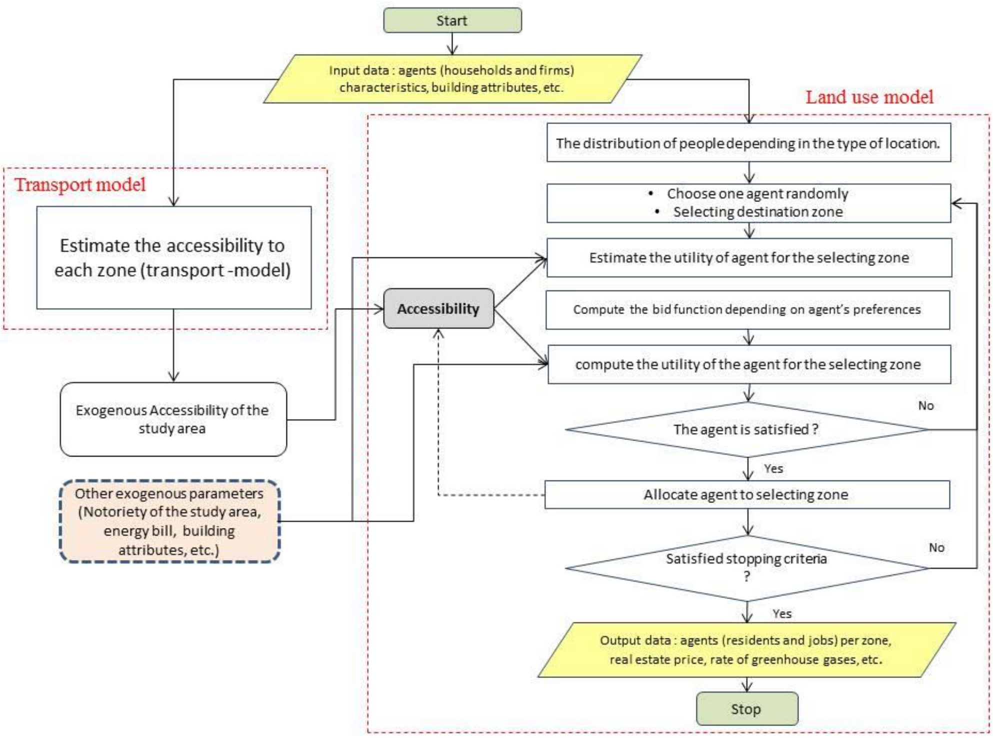

Figure 2: Simplified flowchart of the MUST-B model

At the iteration *n*, the bit that an agent (consumer) *a* makes to move into the area *j* depends on the price of the real estate in its original area *i* and the difference in utilities between zones *i* and *j* at the iteration *n-1*. The agent's willingness to pay can be calculated using the following expression:

$$\pi^{a}_{j,n} = P_{i,n-1} + \delta\left(U^{a}_{j,n-1} - U^{a}_{i,n-1}\right) \quad (1)$$

Where:

- P_i: the real estate price of the Zone *i*,

- U_j^a: utility value associated with new location alternative *j* for the agent *a*,
- δ: Amplitude of the auction, determine the utility gain converted in an additive price of the initial price.

We assume that the agent *a* may choose to remain in its home area *i* if it is offered a discount on the price of the real estate. The expression of this new price is:

$$\pi_{i,n}^{a} = P_{i,n-1}(1-\beta) \qquad (2)$$

3.3. Residential Location Model

Many researchers have considered various factors representing decision-making criteria of households to select target location (Matthews, Gilbert et al. 2007). Lowry rooted his very simple model in the journey to work and the availability of employment (Lowry 1964). Access to services – such as schools, facilities – is another interaction-based element. In this research, the residential location model is based on a hypothesis derived from random utility theory that households choose locations that maximize their utility. Households value different zones as a function of their location environment attributes and the time and goods associated with the activities. The proposed method consists of constructing a residential utility function that integrates household's behavior in their residential location choice and allows households to be allocated to residences using an auction procedure. The residential utility function reflects the satisfaction of the household associated to a given location and type of building.

Our model allows the inclusion of a large number of variables representing the most relevant attributes of households (socioeconomic characteristics), real estate (property types), and the locations (neighborhoods, activities). It depends on several parameters such as the accessibility and notoriety of the area, the surface of the housing, the price of real estate, etc. There is a trade-off of accessibility and environmental characteristics against rent. The utility is constrained by a household's socio-economic class. Within this calculation, the exogenous accessibility (derived from the transport model) is considered to be known and fixed.

The utility function of the household *h* residing in the zone *z* that ascribes utility values to the new home location alternatives has the following general, linear form:

$$U_{h,z} = \alpha_{1_h} AC_z + \alpha_{2_h} NO_z + \alpha_{3_h} SL_h - EB_z * SL_h - P_z * SL_h \qquad (3)$$

Where:

- AC: accessibility of the selecting zone
- Z: index representing new zone of the new location alternatives,
- NO: notoriety of the zone (reflects the quality of neighborhood life and availability of public services such as shopping and schools),
- SL: surface area,
- EB: energy bill related to the housing per m² of the area under consideration,
- P: price per m² of the housing of the area under consideration,
- α_i: utility function parameter to be estimated according to the household's socio-economic class

The households will be allocated in zone where they maximize their utility.

If $U\left(\pi_{j,n}^{h}\right) > U\left(\pi_{i,n}^{h}\right)$ the household h chooses to locate in the zone *j*, otherwise it will remain in the zone *i*. In the case where the zone *j* is already saturated (the zone has reached its total capacity); we will move the household which has the lowest utility from the zone *j* to another destination.

3.4. Economic Activities Location Model

The economic activities location model can be used to determine the distribution of employment in the different zones of the study area. In urban research, economic activities are generally classified into four categories (Coppola, Ibeas et al. 2013): (1) basic sector activities dependent on exporting outside the system, (2) activities aimed at the internal demand, (3) representative activities such as those whose location depends on particularly attractive zonal characteristics for reasons of prestige or centrality, (4) activities with low spatial efficiency that need large areas of land to function correctly.

The proposed method is similar to that of households' location choice. It consists in constructing a job localization function that integrates the behaviors of firms in the choice of location of their workplaces. This localization depends on different factors such as the accessibility to population and workforce, the area's attractiveness, the firm characteristics and activities, the price of real estate, etc. The firm tries to acquire the local that it considers most useful for its activity according to its profit maximization function. So, as for households, we consider the choice that maximizes its utility.

The utility function of the firm *f* (characterized by its size and the sector of activity to which it is attached) located in zone z can be expressed as follows:

$$U_{f,z} = (\lambda_{1_f} AC_z + \lambda_{2_f} NO_z + \lambda_{3_f} RE_z - TT_z * SLe - P_z * SLe) \times S_f \qquad (4)$$

Where:

- Accessibility (AC) of the working population to the zone,
- Notoriety (NO) of the area considered,
- Surface of the desired local (SL),
- Ratio of firms (RE) of the same activity in the area considered,
- Taxes in the area (TT),
- Real estate price (P) per m² ,
- S_f Size of the firm
- λ_i parameters to be estimated according to the activity of the firm

The firms will be allocated in zone where they maximize their utility.

If $U\left(\pi_{j,n}^{f}\right) > U\left(\pi_{i,n}^{f}\right)$ the firm f chooses to locate in the zone j, otherwise it will remain in the zone i. In the case where the zone *j* is already saturated (the zone has reached its total capacity); we will move the firm which has the lowest utility from the zone *j* to another destination, zone *k* for example (see Figure 3).

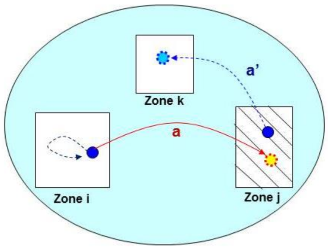

Figure 3: Space Assignment Mechanism

The relocation of an agent affects the composition of the area; neighborhood (in the case of residential use) or the possibility of agglomeration economies (in the case of firms). Since the model modifies these attributes and they can be assessed in a negative as well as a positive manner by the rest of the agents, consumers reevaluate their bid in response to the area's updated characteristics. According to each area characteristics there is the possibility of changing location, because the agent's willingness to pay is altered, either increasing or decreasing. For example, some retail firms would like to be located near the residents/clients who are their clients.

3.5. Accessibility Prediction Model

In the MUST-B Model, Households and firms are interacting via the accessibility variable. The accessibility of households considers the supply of transport (the transport system creates opportunities for interaction or mobility) and the supply of the location of firms (employment opportunities) on the one hand and the accessibility of firms take into account the supply of transport and the location of households (labor force). There is then, in the system, feedback between the two agents (Figure 4). The distribution of accessibility in space, over time co-determines location decisions and so results in changes in the land-use system.

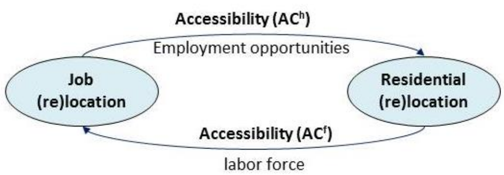

Figure 4: households/firms interaction

The accessibility of a zone comprises two components: one exogenous (land-use transport feedback cycle), which reflects the performance of the transport system and the other endogenous, which reflects the spatial distribution of the population and jobs during the simulation. At this stage, the accessibility associated to the performance of the transport system is calculated using a transport model and is injected into the land-use system as an exogenous parameter. The second part of the accessibility related to the spatial structure (distribution of jobs and population) is determined as follows

(1) The generalized cost of travelling between the zones *i* and *j* using the private vehicle (PV) mode is a combination of the time of travel, the distance travelled, and the actual monetary costs (fuel cost and parking fees). It can be calculated using the following equation:

$$C_{(i,j)}^{VP} = V_t * tt_{(i,j)}^{VP} + \left(CC + CK\right) * d_{(i,j)}^{VP} + C_j^{Park} \quad (5)$$

Where Vt = the time value, tt_{ij} = the time of travel between zones *i* and *j*, $d_{(i,j)}$ = the distance travelled, CC = fuel cost par km, CK = vehicle use costs and C_j^{Park} = the parking fee of the destination area.

(2) The generalized cost of travelling between the zones *i* and *j* using the public transportation (PT) mode is a combination of the time of travel, the number of transfers, and the actual monetary costs. It can be calculated using the following equation:

$$C_{(i,j)}^{PT} = V_t * tt_{(i,j)}^{PT} + Cost^{PT} + \eta * N_{(i,j)}^{Corres} \quad (6)$$

Where Vt = the time value, tt_{ij} = the time of travel between zones *i* and *j*, $N_{(i,j)}$ = the number of transfers, Cost = the travel cost and η = the parameter to be estimated.

The measure of the accessibility is based on a gravity model. It refers to the capacity of a place to reach certain opportunities. The endogenous part of the accessibility for the household measures the population size within the special reach of the employment opportunities. In general, the accessibility the accessibility of a zone can split into two parts. They are denominated as exogenous accessibility calculated using a transport model, and endogenous accessibility or potential reachable opportunities from an area.

The endogenous accessibility for a household of a determined zone to the employment opportunities in the reset of the zones using a private vehicle mode can be calculated using the following expression:

$$Acc_{endog}^{PV}(i) = \mu * \sum_j^n \frac{\text{pop(i)} * jobs(j)}{(C_{(i,j)}^{PV})^2} \quad (7)$$

Where *pop(i)* = the number of residents present in origin zone *i*, *Jobs(j)* = the number of jobs in destination zone *j*, $C_{(i,j)}^{PV}$) = a measure of travel cost by *PV* mode between the origin zone *i* and the destination zone *j* (expression 7), and μ= the parameter to be estimated.

Exogenous accessibility can be represented by

$$Acc_{exog}^{PV}(i) = \theta * \sum_i e^{-C_{(i,j)}^{PV}} \quad (8)$$

Where $C_{(i,j)}^{PV}$ = a measure of travel cost by PV mode between the origin i and the destination j (expression 8), and θ = the parameter to be estimated. Finally, the accessibility of a determined zone to the employment opportunities using a PV mode can be expressed as

$$Acc^{PV}(i) = Acc_{exog}(i) + Acc_{endog}(i) \quad (9)$$

The same process can be used to calculate the accessibility using public transport (PT) mode.
In order to calculate the accessibility of all modes of a determined zone, we must weigh the accessibility of each mode by its modal share. The determination of the modal share is based on the generation-distribution approach (gravity model) of the 4 steps transport model. The estimation of the parameters related to the accessibility indicators is based on the origin-destination survey.

3.6. An agent-based architecture for modeling land use and transport interaction

The agent-based simulation uses database for input, a Discrete Event-based simulation and RStudio to analyze and visualize the output results. The simulation starts with the experiment to simulate. Such experiment includes all agents' attributes and variables. In residential location choice sub-model, a household is modeled as a single agent, and in the economic activities location choice sub-model, a firm is also modeled as an agent. The repository contains all the individual static models. The GENERATOR connects to the input files to retrieve all the configuration information and all agents' static attributes from the experiment. The simulation is driven by an R script to produce a result set, which we processed to conduct statistical analysis and to display results. We use R to processes the results. The result files are used to visualize the simulation and to conduct analysis. The analysis can lead to a new cycle. This allows focusing on critical parameters (agent' preferences, environmental attributes, etc.) that determine the model output (real estate price, land use) (**Figure 5**). This simulation is run using VLE (Virtual Laboratory Environment). VLE software **(Quesnel, Duboz et al. 2009)** implements Discrete Event system Specification (DEVS) M&S and supports multi-modeling, simulation and analysis. It is based on an extension of DEVS, the Dynamic Structure Discrete Event formalism (DSDE) **(Barros 1997)**. The implementation of the DSDE abstract simulators gives to VLE the ability to simulate distributed models and to load and/or delete atomic and coupled models at runtime. It is also possible to perform statistical analysis of results thanks to a plug-in that allows communication between VLE and R **(Quesnel, Duboz et al. 2009)**.

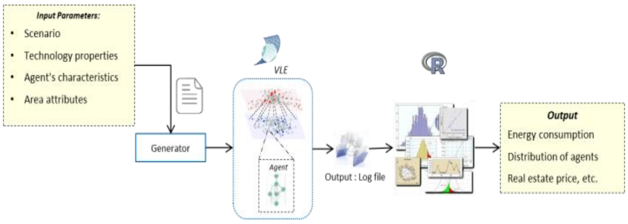

Figure 5: Agent based-modeling and simulation architecture for MUST-B model

4. APPLICATION OF THE MODEL TO THE METROPOLITAN AREA OF BORDEAUX

In order to model household and economic activities location as part of the MUST-B model, we use the agglomeration of Bordeaux as a case study. In this section, we will simulate a simple scenario to predict the urban development in a specific period and test our model functioning.

4.1. Study Area

The Urban Area of Bordeaux (UAB) consists of 191 communes of the counties of Gironde and Landes (called in France "département", a French legal subdivision) and covers an area of 3,901 km². This area contains the Bordeaux metropolis, considered as the central city of the Gironde County, and fifteen small towns located nearby. The area also includes several villages and industrial or touristic regions. Development has occurred mostly in lands around the city and the towns. The area of Bordeaux extends to the ocean and has 1.1 million residents, 523310 households, 467211 jobs and 34676 firms. The vast majority of the population lives in an area under urban influence, i.e., according to INSEE, the French National Institute for Statistics and Economic Research, a metropolitan area within the meaning of commuting from home to work activity.

4.2. Data Preparation

The area is administered by 255 different IRIS, the acronym of 'aggregated units for statistical information' with a target size of 2000 residents per basic unit. These units represent the fundamental unit for dissemination of infra-municipal data. They respect geographic and demographic criteria and have borders which are clearly identifiable and stable in the long term. The zoning used in this study has divided the metropolitan area into 42 zones according to geographic and transportation criteria (see Figure 6). The different sub models will be calibrated with data from 2012, which is taken to be the base year of this research. The data used in estimating the parameters of the different sub-models came from three main sources. The first source was provided by official statistics (INSEE 2012). It collects and publishes information about the activities, jobs and households, and carries out the periodic national census. The second source is the urban planning agency of the Bordeaux metropolis, which have appropriate information on urban planning and development projects and studies the general rules for land use in the territory of the study area. Finally, the third data source consists of a transport survey designed principally by the authors that provided information on the characteristics of the surveyed households and the mobility of each household member. These data are used to characterize demand (households and firms) and supply (housing stock, land, etc.). Some data have been estimated on the basis of demand and supply. For example, the building's energy bill based on the age of the building and the area's notoriety according to public services, Shops, schools, etc.

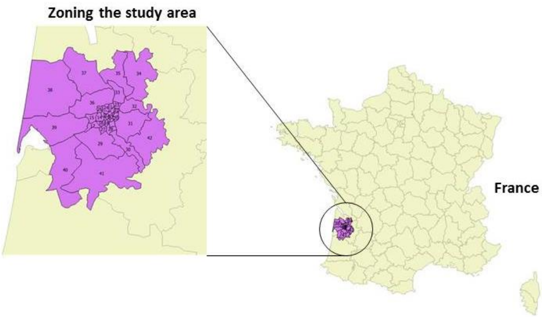

Figure 6: Zoning the study area

The location model for households was disaggregated into 10 subtypes of agents. The households were divided into, two income groups, those with high incomes (socio-professional category+) and those with medium and low incomes (SPC-) and five size groups. This distinction was made to try to obtain better-fitting parameters for the preferences shown by the different agents. The firms were disaggregated into 32 categories, 4 economic activities groups and 8 size categories.

4.3. Result and Discussion

The data required to run the MUST-B model are imported through a series of csv files that can be edited before each simulation cycle. In the present case, a part of the accessibility for activities and population in each zone is exogenous. The exogenous accessibility is based on a transportation model which is an external system related to the study area transport system. The measure of the other part of accessibility and attractiveness is modified at each iteration (each iteration represents a draw) depending on the results provided by residential and job (re)location sub-models. The behavior of these sub-models was implemented in VLE software and programmed using C++ code. An initial procedure (GENERATOR model) imports the exogenous accessibility indicators between the zones, the socio economic data and the neighborhood attributes. A second phase then calculates the real estate price indices as well as the location of households and firms by zone through the location models. On a computer view the agents do not exchange information, and from an economic and social point of view the endogeneity (notion of economic equilibrium) represents the interaction between the agents.

The results set out below are based on UAB data presented in the last section. However, the model is not validated and the results of the simulation of 10 million draws (which is the criteria to stop the simulation) are presented in order to illustrate the functioning of the model and to validate the implementation of the mechanisms.

Figure 7 illustrates the evolution of the real estate prices indicator during simulation. The real state price is modified at each iteration, depending on the results provided by residential and job location sub-models. After a certain number of iterations, the average price of real estate remains stable this means that the model is reached the state of equilibrium according to Wardrop's equilibrium principle in traffic assignment. We also verified through another scenario that the initial point does not affect the price indicator at equilibrium state (see Figure 6). The real estate price indicator is determined by the auction mechanism in an endogenous way.

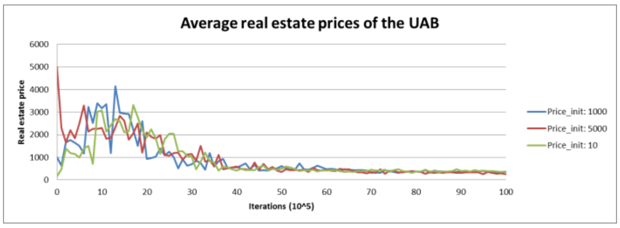

Figure 7: Real estate price indicator

The figure below shows the evolution of the real estate price of the 42 zones of the AUB.

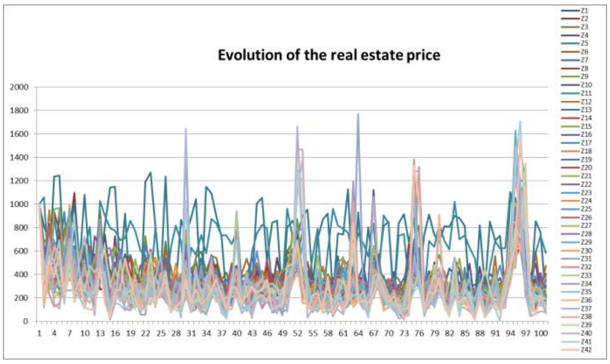

Figure 8: Evolution of the real estate price of the zones

At the beginning of the simulation, the population and jobs are located randomly taking account the capacity of each zone. Then, the MUST-B model is used to predict households location in study area based on the information available on demand, actual real estate supply, building attributes and the corresponding economic incentives. **Figure 9** shows the result of the simulation in terms of aggregated consumer utility obtained by zone. It represents the degree of satisfaction or happiness perceived by all households in a zone. In the **Figure 9**, we observe that the zone 5 (the central city of the urban area of Bordeaux) is very attractive and the households consume the entire supply. This

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attractiveness can be explained by better notoriety (public services, parks, schools, security, etc.) of this area and a good index of accessibility.

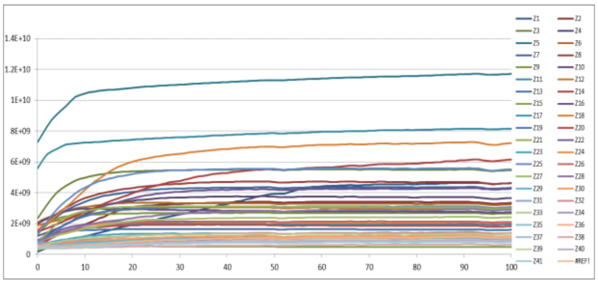

Figure 9: Cumulative utility at the scale of the zones

The Figure below shows the evolution during the simulation of the aggregate utility of households. We observe that the economic equilibrium is reached for the households after 60×10^5 draws.

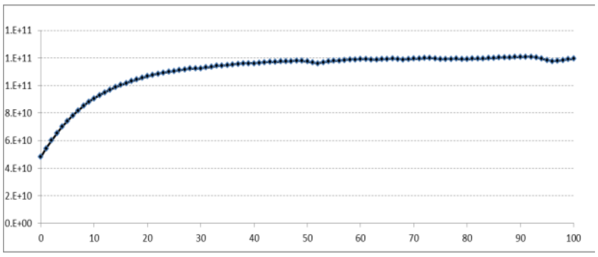

Figure 10: Cumulative utility of the AUB.

In this experiment we have presented the evolution of two indicators: the average price of real estate in the studied area and the location of households by zone. Other important indicators such as firms' (re)location, social mix, energy consumption, greenhouse gas emissions, etc. can be studied in order to analyse their influence on the pattern of land use development.

CONCLUSION

This article has presented a land use and transport interaction model that can perform estimations of changes in the location of population, economic activities, energy consumption, greenhouse gases and real estate prices as a result of the introduction of policies and projects relating mainly to transport. This model aims to provide better decision helping tools for urban and regional long term planning. MUST-B model enables us to construct future scenarios of urban land use in a methodical and practical way, using a mathematical model with solid economic basis. In this study, we developed a new agent-based model for simulating future urban land-use development in our study area, located in the New Aquitaine region of France. In details, MUST-B Model is developed using agent based modeling approach in which the agents are households and firms that seek to localize depending on the utility of the location and the financial constraints. It takes account of the functioning of land and real estate markets and it integrates several mechanisms such as real estate price estimation in an endogenous approach, integration of energy bills (housing and mobility) into the residential location choice model and Taking into account social housing. The different technics employed were previously validated in their respective domain and the models and simulation results proposed in this paper have confronted to expert in the domain. The next step is to make the MUST-B model operational by calibrating it to the urban area of Bordeaux and to validate it based on historical data. The predictive capacity of the MUST-B model will be assessed by confronting simulation results against historical observations that will be not used for calibration. In General, Available data are split between an "estimating" set (data 2012) will be used for model calibration and a "test" set (data 1990) will be used purely for validation.

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REFERENCES

Acheampong, R. A. and E. Silva (2015). "Land use–transport interaction modeling: A review of the literature and future research directions." Journal of Transport and Land Use 8(3).

Ahmed, B. and R. Ahmed (2012). "Modeling urban land cover growth dynamics using multi‐ temporal satellite images: a case study of Dhaka, Bangladesh." ISPRS International Journal of Geo-Information 1(1): 3-31.

Alonso, W. (1960). "A theory of the urban land market." Papers in Regional Science 6(1): 149-157.

Alonso, W. (1964). "Location and land use. Toward a general theory of land rent." Location and land use. Toward a general theory of land rent.

Barros, F. J. (1997). "Modeling formalisms for dynamic structure systems." ACM Transactions on Modeling and Computer Simulation (TOMACS) 7(4): 501-515.

Bin, P. and P. Tao (2010). "Land use system dynamic modeling: literature review and future research direction in China." Progress in Geography 29(9): 1060-1066.

Coppola, P., Á. Ibeas, L. dell'Olio and R. Cordera (2013). "LUTI model for the metropolitan area of Santander." Journal of Urban Planning and Development 139(3): 153-165.

Crozet, Y. and I. Joly (2004). "Budgets temps de transport: les sociétés tertiaires confrontées à la

gestion paradoxale du" bien le plus rare"." Les Cahiers scientifiques du transport(45): pp. 27-48.
Echenique, M. H., A. D. Flowerdew, J. D. Hunt, T. R. Mayo, I. J. Skidmore and D. C. Simmonds (1990). "The MEPLAN models of Bilbao, Leeds and Dortmund." Transport Reviews 10(4): 309-322.
Han, H., C. Yang and J. Song (2015). "Scenario simulation and the prediction of land use and land cover change in Beijing, China." Sustainability 7(4): 4260-4279.
Hosseinali, F., A. A. Alesheikh and F. Nourian (2013). "Agent-based modeling of urban land-use development, case study: Simulating future scenarios of Qazvin city." Cities 31: 105-113.
INSEE. (2012). "Socio-economic data." Retrieved April, 2017, from https://www.insee.fr/fr/statistiques.
Lowry, I. S. (1964). A model of metropolis, Rand Corporation Santa Monica, CA.
Martinez, F. (1996). "MUSSA: land use model for Santiago city." Transportation Research Record: Journal of the Transportation Research Board(1552): 126-134.
Matthews, R. B., N. G. Gilbert, A. Roach, J. G. Polhill and N. M. Gotts (2007). "Agent-based land-use models: a review of applications." Landscape Ecology 22(10): 1447-1459.
Miller, E. J. and P. A. Salvini (2001). "The Integrated Land Use, Transportation, Environment (ILUTE) microsimulation modelling system: description and current status." Travel Behaviour Research: The Leading Edge: 711-724.
Mitton, L., H. Sutherland and M. Weeks (2000). Microsimulation modelling for policy analysis: challenges and innovations, Cambridge University Press.
Newman, P. and J. Kenworthy (1999). Sustainability and cities: overcoming automobile dependence, Island press.
Orfeuil, J.-P. (2000). La mobilité locale: toujours plus loin et plus vite. Les territoires de la mobilité, Presses Universitaires de France: 53-68.
Pagliara, F. and A. Wilson (2010). The state-of-the-art in building residential location models. Residential location choice, Springer: 1-20.
Parker, D. C., S. M. Manson, M. A. Janssen, M. J. Hoffmann and P. Deadman (2003). "Multi-agent systems for the simulation of land-use and land-cover change: a review." Annals of the association of American Geographers 93(2): 314-337.
Pfaffenbichler, P., G. Emberger and S. Shepherd (2010). "A system dynamics approach to land use transport interaction modelling: the strategic model MARS and its application." System Dynamics Review 26(3): 262-282.
Quesnel, G., R. Duboz and É. Ramat (2009). "The Virtual Laboratory Environment–An operational framework for multi-modelling, simulation and analysis of complex dynamical systems." Simulation Modelling Practice and Theory 17(4): 641-653.
Segal, D. (1977). Urban economics, Homewood [Ill.]: Richard D. Irwin; Georgetown [Ont.]: Irwin-Dorsey.
Silva, E. A. (2011). "Cellular Automata and Agent Base Models for Urban Studies: From Pixels to Cells to Hexa- dpi's." Urban remote sensing: Monitoring, synthesis and modeling in the urban environment: 323-334.
Simmonds, D. (2001). The objectives and design of a new land-use modelling package: DELTA. Regional science in business, Springer: 159-188.
Valbuena, D., P. H. Verburg and A. K. Bregt (2008). "A method to define a typology for agent-based analysis in regional land-use research." Agriculture, Ecosystems & Environment 128(1): 27-36.
Waddell, P. (2002). "UrbanSim: Modeling urban development for land use, transportation, and environmental planning." Journal of the American planning association 68(3): 297-314.
Wegener, M. (2004). Overview of land use transport models. Handbook of transport geography and spatial systems, Emerald Group Publishing Limited: 127-146.
Wegener, M. (2011). "The IRPUD model." Spiekermann & Wegener in Dortmund. Available online: http://www. spiekermann-wegener. com/mod/pdf/AP_1101_IRPUD_Model. pdf (accessed on 1 December 2011).
Wooldridge, M. (2009). An introduction to multiagent systems, John Wiley & Sons.
Zhang, Q., Y. Ban, J. Liu and Y. Hu (2011). "Simulation and analysis of urban growth scenarios for the Greater Shanghai Area, China." Computers, Environment and Urban Systems 35(2): 126-139.

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A SIMULATION TOOL TO ASSESS THE INTEGRATION OF CARGO BIKES INTO AN URBAN DISTRIBUTION SYSTEM

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ABSTRACT
The use of cargo bikes for goods deliveries represents a promising concept of urban logistics. In this contribution, a new simulation-based assessment tool integrating this emission free vehicles in urban distribution systems is presented. First, typical schemes are identified and an analysis of the underlying planning problems is conducted. Second, the developed GIS-based discrete-event simulation model and the coupled tour-planning algorithm are described, implementing the pattern of control optimization. To the best of our knowledge, such a tool is not yet existing. Finally, the tool is applied, evaluating the potential use of cargo bikes for B2B-deliveries in the medium size city of Grenoble in France.

Keywords: urban logistics, cargo bikes, delivery network simulation, control optimization

1. INTRODUCTION

Mitigating and fighting climate change has become one of the major challenges of modern societies. To achieve the Paris Agreement (United Nations, 2015) global CO2 emissions shall not peak later than 2020. Urban transport is responsible for 23% of greenhouse gas emissions in the EU (European Commission, 2016). Thus, economies demand the implementation of disruptive actions and a sustainable urbanization everywhere (Rockström et al., 2017). The megatrend of urbanization goes along with serious issues of more congestion, material flows, air pollution and noise exposure. Growing e-commerce and freight volumes (Bogdanski, 2017) put more stress on cities, their inhabitants and infrastructure. Hence, municipalities and logistics operators are under pressure to bring up new solutions to maintain cities liveable.

Urban logistics as an attempt to cope with those challenges is undergoing a renaissance right now. As in reality also in science a growing corpus of work (Evrard Samuel and Cung, 2015; Lagorio, Pinto and Golini, 2016; Dolati Neghabadi, Evrard Samuel and Espinouse, 2016) is a sign mark for that. The cargo bike as new vehicle for urban freight (Gruber, Kihm and Lenz, 2014) is gaining ground. As a zero-emission vehicle it can be suitable for freight transport in dense urban areas like city centres (Conway et al., 2011; Schliwa et al., 2015). It has the potential to substitute 25% of motorized delivery trips (Reiter, Wrighton and Rzewnicki, 2013).

The cargo bike is used for direct transports within cities (Gruber, Kihm and Lenz, 2014) or it can be part of the last (respectively first) mile of a transport chain (Leonardi, Browne and Allen, 2012; Schliwa et al., 2015). Hence, it can become a vital part of urban distribution systems. Since cargo bikes can carry freight of the size of an euro pallet weighing maximally 300kg (Schenk, Assmann and Behrendt, 2017), the transport network needs to be adjusted. In order to replace vans and trucks used before in the last mile, a transhipment point in close proximity to the dense service area needs to be implemented. The setting-up of such a distribution system is imposing a magnitude of challenges concerning the planning of the transport network, locations and processes. Although work has been done on this issue of determining location and network architecture (Janjevic and Ndiaye, 2014, 2016; Agrebi, Abed and Omri, 2015; Rao et al., 2015), a simulation tool for assisting the planning process is missing.

Location selection problems for transhipment points in urban logistics can be classified as a special case of the facility location problem (Rao et al., 2015). The viability of the cargo bike integration is highly dependent on the right structure of network chosen. To deploy it, a profound planning process needs to be carried out. A magnitude of requirements (Agrebi, Abed and Omri, 2015), such as accessibility, connectivity, proximity to costumer etc. on the one hand and a very limited amount of available space in urban areas as costs constraints on the other hand do heavily limit the number of feasible locations. As experience with existing schemes shows, finding a feasible, accepted location for logistic operations in cities is one of the hardest planning tasks. This leads to the fact that the choice of location of transhipment points is rather a matter of availability (Van Duin, Quak and Muñuzuri, 2010) than of sophisticated optimization.

We are therefore aiming at assisting urban distribution planners in rapidly testing appropriate locations. Within the planning process, simulation of prospective configurations of a transport network is a viable method to identify beneficial solutions. The target is to develop a simulation tool, which allows a fast and convenient application. Meaning that a) it implements street maps via GIS-tools to achieve reality-proof route planning, b) it considers possible locations of transhipment points via an interface and c) it works with easy to gather location information and demand patterns of receivers. Demand patterns shall be easy to gather from a heterogonous group of receivers or senders. Therefore, the focus is on key indicators (e.g. avg. demand, maximum demand) which can be obtained by means of surveys.

The paper focuses on presenting an easy to use tool, providing a simulation to evaluate the network-setting of multimodal schemes integrating cargo bike. Therefore, such schemes will be classified and issues of location selection in urban areas will be introduced in section 2. Our GIS-based simulation tool will be presented in section 3. In section 4, it will be applied to and validated on a specific use case in the medium size city of Grenoble in France. Finally, we will draw our conclusion and give an outlook on future work.

2. APPLICATIONS OF MULTIMODAL SCHEMES & PLANNING PROBLEMS INTEGRATING CARGO BIKES

To define our framework of simulation, firstly a classification of cargo bike schemes in urban distribution systems is introduced. Although some authors already worked on the issue of developing a typology (Janjevic and Ndiaye, 2014; Staricco and Vitale Brovarone, 2016), none of them presented a satisfactory approach. Planners however will need to consider and evaluate different network configurations. A clear, unambiguous definition and classification will therefore be a vital assist for those. Those presented below are based on the works of (Benjelloun, Crainic and Bigras, 2010; Allen et al., 2012; Leonardi, Browne and Allen, 2012; Raimbault, Andriankaja and Paffoni, 2012; Janjevic and Ndiaye, 2014; Crainic and Montreuil, 2016; Staricco and Vitale Brovarone, 2016; Schenk, Assmann and Behrendt, 2017).

The basic concept of such schemes is to transfer freight from the outside of a city to the cargo bikes which are doing the tour in the urban area. The points outside the city are coined depots. Depots are distribution centres or warehouses (Anand et al., 2012) of single or multiple enterprises and can also be production sites.

The basic element of such a distribution system is the transhipment point (TP) which appears in different types. The most common utilization is an urban consolidation centre (UCC) (Allen et al., 2012; Holguín-Veras and Sánchez-Díaz, 2016). In UCCs, freight of different shippers, consignees, and carriers from different depots is consolidated into the same vehicle (Benjelloun, Crainic and Bigras, 2010). However, schemes without a consolidation function at the transhipment point do exist as well. Those will be named transit points. Having define these terms, a clear classification of multi modal schemes integrating cargo bikes in urban distribution systems is developed. The first class is direct transports (2.1). The second and third class are single-level (2.2.) and two-level (2.3.) systems (figure 1).

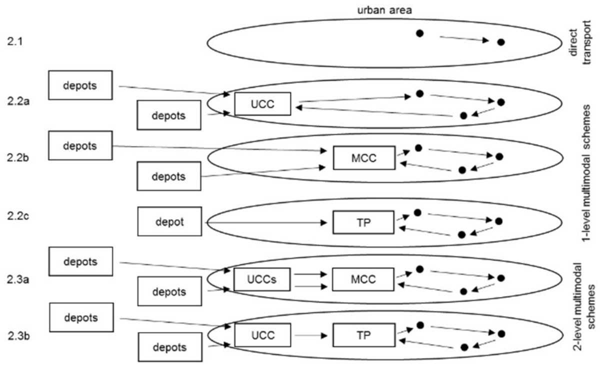

Figure 1: Classification of multimodal schemes integrating cargo bikes according to level and consolidation principle.

2.1. Direct urban distribution schemes

This class of cargo bike schemes contains all relations of transports where the freight is not transferred between vehicles when going from its origin to its destination. Cargo bikes can be used for point to point services and for delivery runs. Point to point service also entails trips where drivers combine several A to B relations in one cargo bike, as courier services do. Since no transhipment takes place, no consolidation in the defined sense does happen. Those transports are usually restricted to a city. As examples can be found: transports on own account or delivery rides by local businesses.

2.2. Single-level urban distribution schemes

A single-level multimodal scheme is characterized by one transhipment process between the origin and destination. Typically, freight is sent by a lorry from the origin, a depot outside the urban area, to a transhipment centre in close proximity of the delivery zone and changes to the cargo bike. The point of transfer needs to be distinguished in three classes having a significant impact on processes and goods handled, as introduced below. This can either happen at a UCC, a micro-consolidation centre (MCC) or transit point (TP).

a) Depot – UCC scheme

Scheme a in the single-level class is characterized by its UCC. Those facilities are well-known in terms of city logistics (Allen et al., 2012). The primary focus is on the consolidation of freight designated to the city (centre) on specific vehicles for the last mile. They are mostly located at the city edge. Vehicles do not need to be cargo bikes, it can also be electric vehicles or others since some UCCs have already existed for years and decades. At the UCC, freight of nearly all sizes is transferred and consolidated. The facility itself needs to have space and equipment for those, like pallet trucks or forklifts. Examples of depot - UCC schemes are *La Petite Reine* in

Paris and *Last Mile Leeds* in Leeds (Staricco and Vitale Brovarone, 2016).

b) Depot – MCC scheme
As for UCC, MCC is a widely used and well-known term within cycle-logistics. However, MCC is not clear and unambiguous. It is broadly defined as a very small UCC for transferring and consolidating parcels (Browne, Allen and Leonardi, 2011; Janjevic and Ndiaye, 2014). Since it has a variety of shapes and realization, these two functions which come together at a special point of space and the freight characteristic are taken as unique attribute. Its size can equal a container or smaller, a rooftop is not necessary and it can be either mobile or stationary. Due to its size, it can be in closer proximity to the delivery area and is connected to a depot. Examples are *Bento Box* in Berlin (Weber, Chiadò and Bruening, 2012) and *Gnewt Cargo* in London (Leonardi, Browne and Allen, 2012).

c) Depot – TP scheme
This scheme c is similar to b, but it differs in one core function. A transit point (TP) does not fulfil and allow the consolidation of goods. In contrast to UCC or MCC, just one shipper or carrier uses such a facility, where no flows of goods are consolidated or stored. This network is defined by a depot from where freight is shipped to a transit point at which the load changes to cargo bikes. Such a scheme allows crossdocking processes (Gudehus, 2012) where pre-packed load units are transferred. Examples for TP-schemes are *UPS* in Hamburg (Harris and Haycock, 2017) or *GLS* in Budapest (Zsolt, 2017)

2.3. Two-level urban distribution schemes

A two-level scheme is defined by two transfers of freight between the outside and the urban delivery area. A UCC is placed at the city-edge consolidating freight to and from depots outside the city. Within the city several MCC or TP are installed to allow another transfer on cargo bikes for the last mile. Those are in very close proximity to the city centre. Such a system can make sense if urban areas are large, inappropriate distances for cargo bikes between the already set up UCC and the delivery area exist or special modes of transport like barges can be used.

a) Depot – UCC – MCC scheme
In this scheme, a UCC consolidates incoming freight of several carriers. Although it is located between the city edge and the delivery area, it makes sense to install additional MCC in closer proximity to the actual delivery area. The MCC can be either stationary or mobile, allowing the transport vehicle of the latter to form the MCC itself.

b) Depot – UCC – TP scheme
In contrast to the scheme above, this one is just a consolidation process at the UCC. The second stage of transhipment just allows the transfer of freight or load carriers and no consolidation. An example is *Vert Chez Vous* in Paris (VNF, 2015; Staricco and Vitale Brovarone, 2016).

2.4. Special aspect of integrating cargo bikes

Cargo bikes do have other routing characteristics as conventional vehicles. Basically they can also drive on footpaths, pedestrian zones and cycle lanes (Hertel et al., 2014). This point should be represented in Vehicle Routing Problems (VRP) based on urban street networks. It becomes more important as cargo bikes are meant to perform best in urban areas that have high density, narrow streets, with limited access and higher percentages of pedestrian zones (Schliwa et al., 2015). Furthermore no general knowledge on maximal, viable distances between the transhipment point and the delivery area is existing, (Staricco and Vitale Brovarone, 2016). This aspect and a trade-off between the benefits of more complex cycle logistics schemes (2-level) and their increasing costs provide little determinants for planning processes.
Hence, a simulation tool as proposed in the following section is a vital assistance for city planner and logistic operator to integrate cargo bikes in urban distribution systems.

2.5. Location selection and vehicle routing in urban logistics

Transportation costs take a big share in the overall cost of a distribution system. Thus, it makes sense to treat them carefully and precisely no matter which overall planning and decision making methodology is applied.
One mean to get cost values for urban transhipment points can be the application of Operations Research methodologies. The body of methods and algorithms is rich (Rao et al., 2015). They predominantly focus on minimizing costs or improving the service level. (Lagorio, Pinto and Golini, 2016) found 45 vehicle routing problems (VRP) for urban areas, but none could be linked to cargo bikes. (Crainic, Ricciardi and Storchi, 2004) introduced a capacitated multi-commodity location problem formulation for a depot – TP scheme. They do consider two types of vehicle in the linear optimization, one conventional truck and one city freighter which is designed for dense areas.
(Mancini, 2013) is highlighting the importance of multi-echelon distribution systems in urban logistics. Corresponding optimization problems are the Two Echelon Location Routing Problem (2E-LRP) and the Two Echelon Vehicle Routing Problem (2C-VRP), also described by (Gonzalez-Feliu, 2008). Examples from the field of cargo bikes are the above presented cargo bike schemes 2.3a and 2.3b where the goods are consolidated and transhipped. Solving methods for these complex problems frequently include meta-heuristics and decomposition approaches (Prodhon & Prins, 2014).
Since dynamic and stochastic problem environments such as urban logistics can be difficult to model with the help of standard problem formulations, the integration of optimization methods with simulation techniques can provide substantial benefits by offering the possibility to

evaluate solution candidates using simulation models, as shown by (Aurich, Nahhas, Reggelin, & Tolujew, 2016). Furthermore, optimization algorithms can be used to solve problems arising during a simulation run (Affenzeller, et al., 2015). Within the field of urban logistics, discrete-event simulation methods represent a promising approach, enabling the impact assessment of solutions and measures before implementation. A review on simulation techniques for evaluating urban distribution solutions is given by (Karakikes & Nathanail, 2017).

3. DESIGN AND IMPLEMENTATION OF A SIMULATION-BASED DISTRIBUTION NETWORK ASSESSMENT TOOL

The scope of the tool as outlined in the introduction is to provide a fast, true to reality and easy to use simulation to test a certain distribution network scheme with some locations, considering the volatility of demands. For these purposes, two factors are of great importance. Firstly, current linear location selection methodologies work well under a certain environment. However, demand patterns of receivers, either in location of single entities or in volatility of good flows are dynamic. Secondly, non-linear multi-criteria decision making methodologies are gaining ground since they are able to represent the complexity of urban environments with their numerous stakeholders and influencing factors. However, these methodologies are typically based on the judgements of experts, which may not be unbiased or completely correct. As conclusion can be drawn that a methodology is of use, which enables decision makers to test different network configurations, improving their understanding and judgement of the system.

In order to provide support during the planning process, the following requirements have to be met:

- Definition of locations for receivers (also referred to as “customers”), depots and transfer points
- Consideration of stochastic demand patterns
- Modelling and simulation of a distribution network with multiple levels and different means of transport
- Integration of real street maps to provide realistic distance data and visualization
- Calculation of key indicators on distances, cost and environmental impact of the network for comparison of different alternatives

Figure 2 depicts the developed approach. The modelled logistics system represents a hierarchical distribution network with non-nested service varieties. The corresponding vehicle routing problem can be characterized as a 2-echolon VRP (2E-VRP) which is decomposed into Capacitated Vehicle Routing Problems with Multiple Depots (MDCVRP). The simulation model used for demand generation and delivery simulation is implemented using ANYLOGIC simulation software.

For reasons of simplicity and controllability, the implemented tour planning algorithm does not consider time windows for deliveries, vehicle range constraints, multi-dimensional capacity constraints and capacities of transfer points. Nevertheless, the behaviour of the system concerning these aspects is observed as well during the simulation, making it possible to detect infeasibilities occurring in a configured network.

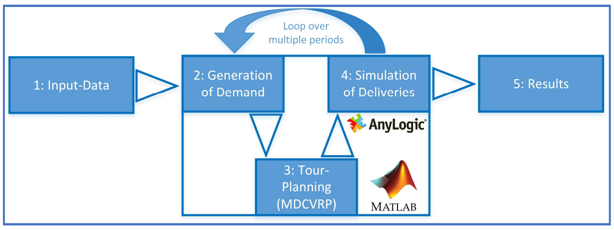

Figure 2: Approach for distribution network evaluation.

3.1. Input data

As a basis for any calculation, the below-listed information on nodes and vehicles of the distribution network must be provided (table 1). Additionally, the number of simulated periods (days) must be specified. The modelled network may consist of one or multiple levels, whereby higher-level nodes act as sources to supply nodes of the next-lower level. That way, typical multimodal schemes with consolidation and transhipment points can be modelled. Input data is imported automatically at the start of the simulation when provided in form of an Excel spreadsheet. Subsequently, nodes are created and animated on an Open-Street-Map (OSM), using the GIS-integration feature of the simulation software.

Entity	Category	Unit
Node	Location	Latitude, Longitude
	Network Level	0: Customer 1: Transhipment-Point 2: Consolidation Centre
	Order Frequency (Level 0 Nodes)	Min. & Max. Time between orders (days)
	Demand (Level 0 Nodes)	Min. & Max. Volume per order (m^3)
		Min. & Max. Weight per order (kg)
Vehicle	Routing-Type	Car / Cargo bike
	Capacity	Max. Weight (kg) & Volume (m^3)
	Velocity	Speed in (m/s)
	Network Level	Network level on which vehicles are in use
	Number	# of vehicle units in use
	Loading/Unloading Times	Time per stop
	Environmental Impact	CO2-emissions per km
	Economic Impact	EUR per km

Table 1: Input-Data on the simulated distribution network.

3.2. Generation of demand

First step in every period of the simulation is the generation of demand on the customer level where each node releases orders at a specified frequency. Weight and volume of an order are randomly generated according to a uniform distribution, specified by the corresponding input parameters. By multiplying the volume of an order with the vehicle-specific average load density (kg/m³), the dimensional weight is calculated (ups.com, 2017). Taking the maximum of dimensional and actual weight of an order reduces the dimension of the demand and simplifies the tour planning while considering capacity constraints of the vehicle in use.

3.3. Tour planning

Second step is the determination of tours to deliver ordered amounts from level-1 nodes to customer nodes. Therefore, information on location and demand of the customer nodes, capacity and routing type of the vehicle, and location of the level-1 nodes is submitted to an external tour planning application. Distance matrices for the different types of vehicles are obtained using the online routing functionality of OSM.

Figure 3 depicts all steps of the tour planning algorithm. Vehicle routing problems with multiple depots are known to be NP-hard (Ombuki-Berman & Hanshar, 2009). In order to quickly provide a feasible solution a heuristic approach is proposed. The MDCVRP is first decomposed into multiple single-depot CVRPs by assigning every customer to its nearest depot. In a second step, the vehicle capacity-exceeding share of demand of every customer is scheduled to be delivered by direct return trips, splitting the demand in slices of the capacity of the vehicle. This simplification seems legit, since delivered goods should be multiple units in most cases and therefore divisibility should be given to a certain degree.

The share of demand inferior to vehicle capacity is considered not to be divisible. This way, a minimal number of stops for each customer can be ensured. Tours to deliver the remaining part of the demand are obtained using a sequential version of the well-known savings algorithm (Clarke & Wright, 1964), extended to handle the case of asymmetric distance matrices, even though there may be major reductions in effectiveness in this case as shown by (Vigo, 1996).

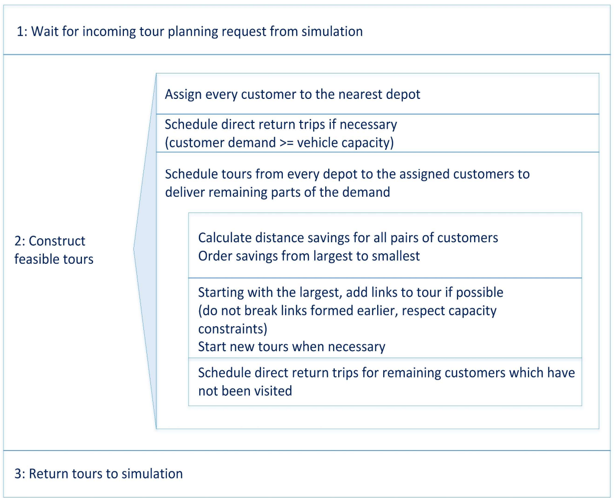

Figure 3: Solution procedure of the tour planning algorithm.

This heuristic constructing feasible tours is implemented using MATLAB, set up as a TCP/IP server to which the simulation (ANYLOGIC) connects as a client, following the idea of control optimization, also referred to as online optimization, described by (Affenzeller, et al., 2015). In order to get a realistic behaviour of the simulation, optimization algorithms are used to solve problems arising during the simulation run. The simulation and tour planning application coupling simplifies improvements of the algorithm and allows parallelism. Due to the TCP/IP interface, optimization algorithms may be implemented on different platforms and executed on different machines.

Constructed tours are returned to the simulation. The sum of all amounts of goods which have to be delivered from a level-1 node to customer nodes determines the level-1 nodes' demand, which has to be supplied from level-2 nodes. The set of demanding level-1 nodes and the set of supplier nodes is again submitted to the tour planning application, as well as characteristics of the vehicle in use on this second level. In this manner, the tour planning application is used to subsequently determine the tours on every level of the network.

Figure 4 shows a simple example of an arbitrary 2-level network with scheduled tours. Demands of level-1 nodes are determined by the 1st level tours to the customers. In the second iteration of the tour planning, 2nd level tours are calculated, starting from level-2 nodes.

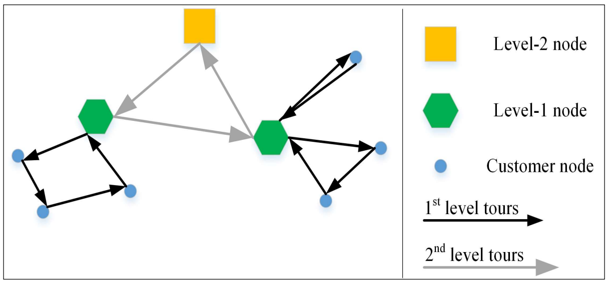

Figure 4: Example of a 2-level network with delivery tours.

3.4. Simulation of deliveries

The execution of the tours on the different network levels is simulated and animated, respecting the given number of available vehicles as well as their velocity and stop times. The logic is programmed using discrete-event and agent-based concepts from the ANYLOGIC simulation environment. In case the number of vehicles is not sufficient to execute all the tours of a day, this deficiency is reported to the user. The execution of the tours is simulated on the underlying street-map, taking into account characteristics of the road network and specific means of transport. The use of different IRouteProvider objects from the simulation library for bikes and cars enables the consideration of the different routing characteristics. Figure 5 shows a screenshot of the interface of the simulation tool in use for the case study.

The animation of the tours eases not only the presentation of new delivery concepts and communication with stakeholders, but also verification and validation of the tool. To ensure flawless functioning, various tests of the

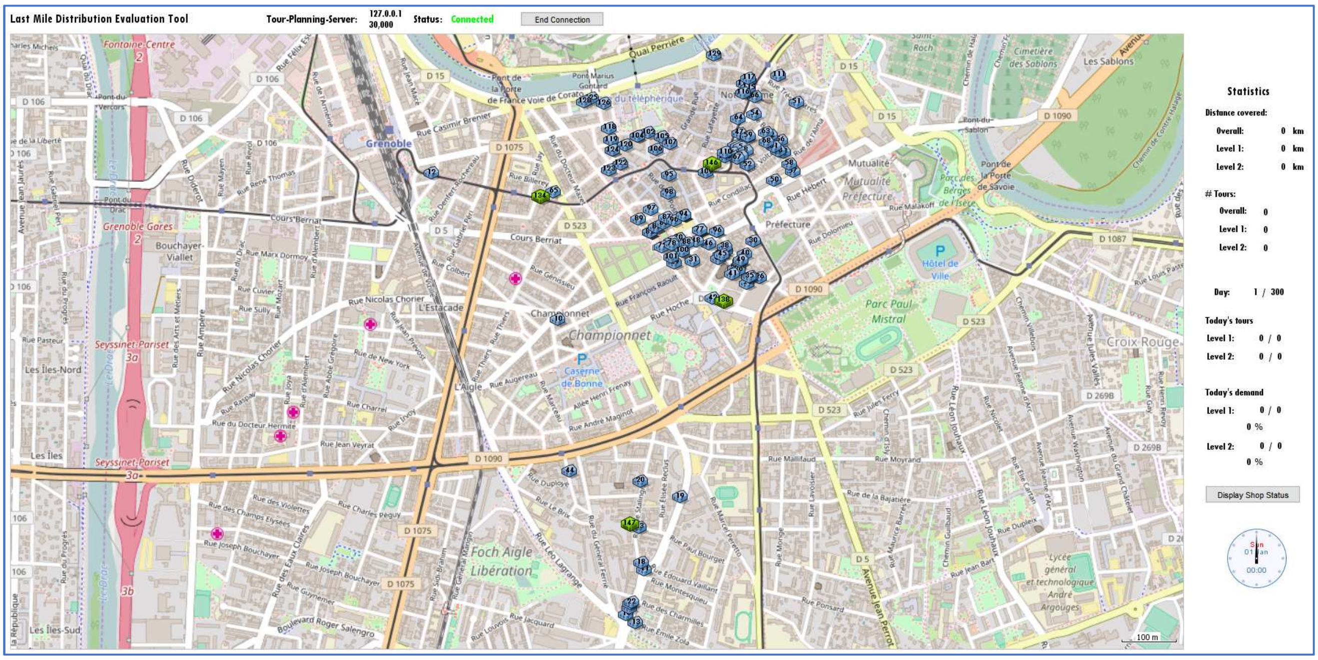

Figure 5: Interface of the GIS-based simulation model, showing a map with 127 shops (blue) and 4 transhipment points (green) from the case study.

optimization algorithm and the simulation model have been carried out and results have been checked. Furthermore, the results of the case study described in section 4 were compared to the ones obtained during the actual implementation of a similar type of network.

3.5. Output Data

In order to gather data on the performance of the distribution (or collection) network with respect to fluctuating demands, the pattern of demand generation, tour planning, and simulated execution is iterated over the specified number of periods. Based on the mileage of each type of vehicle on the different levels the CO2-emissions and transportation costs of the evaluated network are calculated. Furthermore, the time periodically needed to complete all tours gives a clue about the number of vehicles needed on each network level to be able to guarantee certain service levels. The amount of goods transhipped by different nodes indicates their importance and the requirements on their performance and capacity.

By simulating the execution of tours in the modelled distribution network, the general feasibility of the use of cargo bikes can be validated with help of the simulation, even though some real-life constraints such as vehicle range and time windows for deliveries have been excluded from the optimization.

4. CASE STUDY: DEVELOPING A B2B CYCLE-LOGISTICS NETWORK IN GRENOBLE CITY

The following subsections present the application of the developed tool to support currently conducted research on the potential use of cargo bikes for goods delivery to shops (B2B) in the centre of Grenoble city in France.

4.1. Initial situation & survey

There are several characteristics of the city making the implementation of modern city logistics concepts such as cargo bike deliveries in this particular place extremely interesting. First, there is the bowl shape of the city, resulting in a poor, some days alarming air quality (lametro.fr, 2017). Consequently, political efforts are made which target the reduction of traffic and its emissions. Another reason is the narrow city centre with a high number of one-way streets and pedestrian zones which are leading to challenging conditions for traditional forms of deliveries.

In 2016, a survey conducted by the laboratories CERAG and G-SCOP has been carried out within the framework of their research project ULIS (Urban Logistics: Integrated Solutions). This survey investigated the logistics requirements and the demand patterns of 183 shops from various sectors in the centre of Grenoble city. It was determined that a majority of over 80% of the shops is delivered using small boxes or parcels which makes a delivery using cargo bikes generally possible.

For the calculation 127 of the initially 183 shops have been selected, excluding shops with load units other than parcels. Furthermore, pharmacies have been excluded since they are assumed to be supplied by a dedicated distribution network.

Delivery frequencies of the selected shops vary from daily to monthly, the number of units per delivery is between one and more than ten. More than 80% of the shops prefer to be delivered in the morning from 6-10am, leaving a time window of approximately 4h for the deliveries.

Weight and volume of the orders of a shop are assumed to be evenly distributed. The corresponding minimal and maximal parameter values were estimated for every shop based on the type of business and the nature of the ordered goods. Orders of the shops are generated according to the given frequency and to the parameter values of the probability distributions. Figure 6 shows a sample of 300 days and the demand of the shops calculated in the scenarios. Values are aggregated on a daily basis and sorted in ascending order. Simulation runs were carried out with a fixed random seed and the dimensional weight is calculated the same way for all vehicles. Thus, the demand values are the basis for all simulated scenarios.

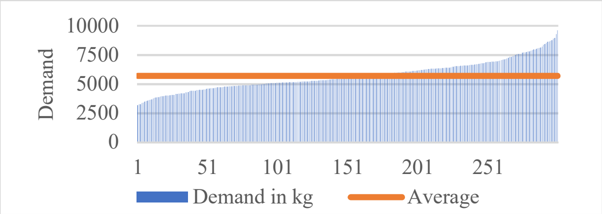

Figure 6: Daily demand of the shops over 300 days.

4.2. Calculated scenarios

In order to assess the feasibility of the use of cargo bikes for delivery, two scenarios have been developed:

1. Reference scenario (1-level), using conventional vans
2. Multimodal scenario (2-level), using trucks and cargo bikes

It is assumed that all incoming goods have been consolidated at a UCC which was established in 2016, located at about 12km northwest of Grenoble city. Table 2 lists the different means of transport and their characteristics.

	(Scenario 1)	(Scenario 2)	
	Van	**Truck**	**Cargo bike**
Max. load	1800kg	4500kg	180kg
Max. vol.	10m³	25m³	1m³
Avg. speed	14m/s	14m/s	3m/s
Number	3x	1x	6x
Routing	Car	Car	Pedestrian

Table 2: Means of transport used in the case study.

The data on cargo bikes represent realistic values, easily reached by modern, electrically supported models (Schenk, Assmann and Behrendt, 2017). Values of stop times are estimated. In this case study, unloading stop times are assumed to be composed of a fixed share of 3 minutes and a variable share of 0.5 seconds per kg demand unit transferred during the stop of every vehicle. For loading the fixed share is estimated at 5 minutes. This is leading to an overall time of 20 minutes for a van and 6.5 minutes for a cargo bike to get fully loaded.

In scenario 1, vans are used to deliver goods directly from the UCC to the shops. As shown in Figure 7, the daily number of scheduled tours varies between 2 and 6, depending on the amount of requested goods. Days are ordered as presented in Figure 6. On average, 12.2 shops are visited per tour and the 3 vans need 149 minutes to finish all tours. The time window of 4h is never violated. The average tour length is 27.9km which is mainly determined by the distance from the UCC to the city centre.

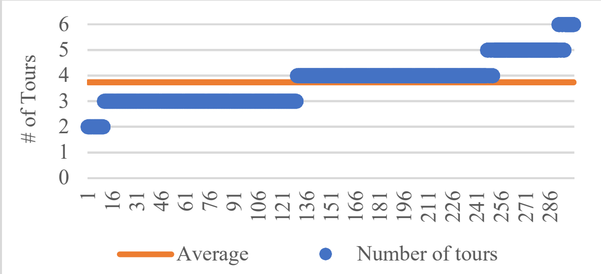

Figure 7: Number of daily tours in the reference scenario.

In scenario 2, 4 spots which are used as transfer points are proposed. They are strategically well located close to a high number of shops in the city centre. The points have been selected by hand from existing stations of a postal company, assuming that they are able to provide space and infrastructure for transhipment. A bigger truck is used to supply these transfer points where goods are transhipped and then delivered to the shops using cargo bikes. This type of distribution network can be classified as a two-level multimodal logistics scheme type 2.3b. Due to the higher capacity of the truck compared to the van, the number of tours on the first level decreases as depicted in Figure 8.

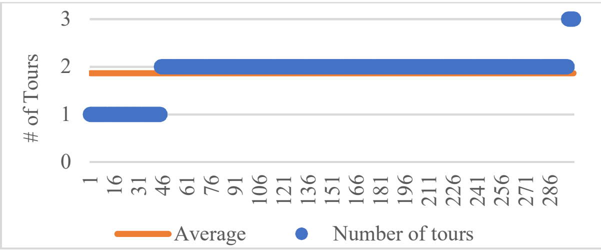

Figure 8: Number of daily tours of the truck in the multimodal scenario 2.

The number of daily tours of cargo bikes on the 2nd level is depicted in Figure 9. As it can be expected from the capacity which is 1/10 of the vans' capacity, the number of necessary tours increases accordingly. The limited capacity leads to a share of 70% of direct return trips visiting only one shop. During the remaining 30% of the tours, 3.4 shops are visited on average; maximum is 11. Due to the proximity of shops and transfer points and because of the limited capacity of the cargo bikes the maximum tour length reaches only 2.5km.

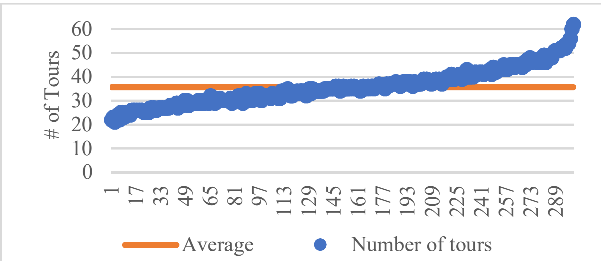

Figure 9: Number of daily tours of the cargo bikes in the multimodal scenario 2.

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Figure 10 shows the time needed by the 3 vans or the 6 cargo bikes to deliver all goods to the shops (and to the transfer points in case of the truck). As expected, the time starts to correlate with the number of tours and the demand if the number of tours exceeds the number of available means of transport.
Even though the overall capacity of the 6 cargo bikes is way less than the capacity of the 3 vans, the proximity of the transfer points and the shops as well as the possibility to use shorter routes lead to a decreased time to deliver the goods to the shops. The higher amount of time needed to deliver the goods by truck to the transfer point is caused by the lowered overall capacity of one truck compared to the 3 vans. This does not necessarily need to cause problems, provided that the truck tours start early enough and assumed that there is sufficient storage space at the transfer points.

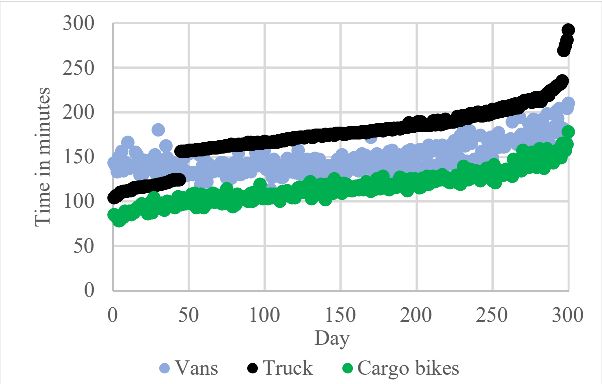

Figure 10: Daily time in minutes to deliver all goods.

In order to evaluate the influence of the number and location of the transfer points, a variation of scenario 2 has been created (scenario 2b). This scenario assumes that transfer point 146 (north east in the city centre, see figure 5) is not available anymore, reducing the number of transfer points to 3. As a result, the average tour length of cargo bike tours increases by 50%. Nevertheless, the general feasibility of the cargo bike delivery concept is still given, since the maximum tour length does not exceed 3.3km.

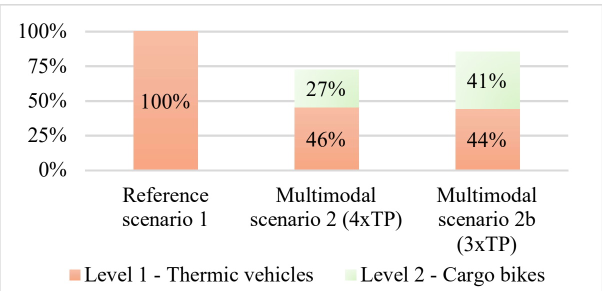

Figure 11: Normalized overall distance driven on different levels.

Figure 11 shows the overall distance driven on the different levels compared to the reference scenario. With the help of the simulation tool, the potential impact of a consequent use of cargo bikes for B2B last-mile deliveries has been calculated, quantifying a possible reduction of the kilometres driven by thermic vehicles of about 55%. This reduction in mileage can be explained by the significantly decreased number of tours from the UCC to the city centre caused by the increased capacity of the truck in use on this relation
The reduction would not only result in decreased local CO2-emissions and an improved air quality, but also in lowered traffic congestion.
The decreasing overall mileage indicates an economic viability of a 2-level multimodal logistics scheme, since driver wages can be assumed to slightly decrease as well because of the lower qualification level needed (Assmann & Behrendt, 2017). Nevertheless, further research on the cost of deployment and operation of transhipment points needs to be carried out for corroboration. The calculated reduction rate in mileage is similar to the one obtained while actually implementing a similar type of network during a pilot study in London, GB in 2010 (Leonardi et al. 2012).

5. CONCLUSION & FUTURE WORK

The use of cargo bikes for goods deliveries represents an interesting concept of urban logistics. Within this contribution, a simulation-based assessment tool for multimodal distribution schemes has been presented and applied to evaluate the use of cargo bikes in the case study of Grenoble city in France.
The presented simulation tool is able to simulate deliveries in multi-level networks in order to estimate network performance as well as environmental and economic impacts. Applied to the case study, the tool revealed the potentials inherent in a two-level multimodal logistics scheme for B2B goods deliveries in Grenoble city using cargo bikes for the last mile deliveries. Even though it is obvious that aiming at a fully consolidated and cargo bike-based last-mile delivery may not be realistic, the above presented case study shows the existing potentials to be exploited by a consequently oriented policy.
The results of the simulation are subject to several biases caused by simplifications, estimations and the simple heuristics used, leaving room for further improvements. Despite the imposed inaccuracies, the developed tool shows that simulation can provide substantial benefits for the assessment of complex multimodal distribution systems arising in urban logistics.

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REFERENCES

Affenzeller, M., Beham, A., Vonolfen, S., Pitzer, E., Winkler, S., Hutterer, S., Wagner, S. (2015) Simulation-Based Optimization with HeuristicLab: Practical Guidelines and Real-World Applications. In M. Mota, D. I., & D. Serrano (Eds.), Applied Simulation and Optimization (pp. 3-38). Springer International Publishing Switzerland.

Agrebi, M., Abed, M. and Omri, M. N. (2015) 'Urban distribution centers' location selection's problem: A survey', 4th IEEE International Conference on Advanced Logistics and Transport, IEEE ICALT 2015, pp. 246–251.

Allen, J., Browne, M., Woodburn, A. and Leonardi, J. (2012) 'The Role of Urban Consolidation Centres in Sustainable Freight Transport', Transport Reviews, 32(4), pp. 473–490.

Anand, N., Yang, M., Van Duin, J. H. R. and Tavasszy, L. (2012) 'GenCLOn: An ontology for city logistics', Expert Systems with Applications. 39(15), pp. 11944–11960.

Assmann, T., & Behrendt, F. (2017)(accepted). Modelling the optimal container heights for cargobikes in intermodal crossdocking schemes for last mile deliveries. *10th International Doctoral Students Workshop on Logistics* . Institute for Logistics and Material Handling Systems, University Magdeburg.

Aurich, P., Nahhas, A., Reggelin, T., & Tolujew, J. (2016) Simulation-Based Optimization For Solving A Hybrid Flow Shop Scheduling Problem. Proceedings of the 2016 Winter Simulation Conference, pp. 2809-2819.

Benjelloun, A., Crainic, T. G. and Bigras, Y. (2010) 'Towards a taxonomy of City Logistics projects', Procedia - Social and Behavioral Sciences, 2(3), pp. 6217–6228.

Bogdanski, R. (2017) Bewertung der Chancen für die nachhaltige Stadtlogistik von morgen - Nachhaltigkeitsstudie 2017. Berlin: Bundesverband Paket & Expresslogistik BIEK.

Browne, M., Allen, J. and Leonardi, J. (2011) 'Evaluating the use of an urban consolidation centre and electric vehicles in central London', IATSS Research. International Association of Traffic and Safety Sciences, 35(1), pp. 1–6.

Clarke, G., & Wright, J. (1964). Scheduling of Vehicles from a Central Depot to a Number of Delivery Points. Operations Research, 12 (4), pp. 568-581.

Conway, A., Fatisson, P.-E., Eickemeyer, P. and Cheng, J. (2011) Urban Micro-Consolidation and Last Mile Goods Delivery by Freight-Tricycle in Manhattan: Opportunities and Challenges, Transportation Research Board 91st Annual Meeting 2012.

Crainic, T. G. and Montreuil, B. (2016) 'Physical Internet Enabled Hyperconnected City Logistics', Transportation Research Procedia, 12, pp. 383–398.

Crainic, T. G., Ricciardi, N. and Storchi, G. (2004) 'Advanced freight transportation systems for congested urban areas', Transportation Research Part C: Emerging Technologies, 12(2), pp. 119–137.

Dolati Neghabadi, P., Evrard Samuel, K. and Espinouse, M. (2016) 'City Logistics : A Review and Research Framework', in RIRL 2016 EPFL. Lausanne.

Van Duin, J. H. R., Quak, H. and Muñuzuri, J. (2010) 'New challenges for urban consolidation centres: A case study in The Hague', Procedia - Social and Behavioral Sciences, 2(3), pp. 6177–6188.

European Commission (2016) Communication from the the commission to the european parliament, the council, the european economic and social committee and the committee of the regions - A European Strategy for Low-Emission Mobility. Brussels.

Evrard Samuel, K. and Cung, V.(2015) 'Towards Evaluation Tools for Last Mile Delivery Projects', I-NUF, 6th METRANS International Urban Freight Conference, October 21-23, 2015. Long Beach.

Gonzalez-Feliu, J. (2008). Models and Methods for the City Logistics: The Two-Echelon Capacitated Vehicle Routing Problem. Turin, Italy: Politecnico di Torino.

Gruber, J., Kihm, A. and Lenz, B. (2014) 'A new vehicle for urban freight? An ex-ante evaluation of electric cargo bikes in courier services', Research in Transportation Business and Management, 11, pp. 53–62.

Gruber, J. and Rudolph, C. (2016) Untersuchung des Einsatzes von Fahrrädern im Wirtschaftsverkehr. Abschlussb. Berlin: Institut für Verkehrsforschung, Deutsches Zentrum für Luft- und Raumfahrt.

Gudehus, T. (2012) Logistik 2. Berlin, Heidelberg: Springer.

Harris, P. and Haycock, R. (2017) 'Sustainable Urban Logistics', in European Cycle Logistics Conference (ECLF 2017). Vienna.

Hertel, C., Spott, M. and Nottelmann, G (2014) Leitfaden Lastenräder einsetzen: bei Großveranstaltungen, in Großeinrichtungen. Fulda: 35. Dt. Evang.Kirchentag 2015 e.V.

Holden, R. and Liversedge, J. (2014) Landscape Architecture : An Introduction. London: Laurence King Publishing.

Holguín-Veras, J. and Sánchez-Díaz, I. (2016) 'Freight Demand Management and the Potential of Receiver-Led Consolidation programs',

Transportation Research Part A: Policy and Practice, 84, pp. 109–130.
Janjevic, M. and Ndiaye, A. (2016)(InPress) ‘Investigating the theoretical cost-relationships of urban consolidation centres for their users’, Transportation Research Part A: Policy and Practice.
Janjevic, M. and Ndiaye, A. B. (2014) ‘Development and Application of a Transferability Framework for Micro-consolidation Schemes in Urban Freight Transport’, Procedia - Social and Behavioral Sciences, 125, pp. 284–296.
Karakikes, I., & Nathanail, E. (2017) ‘Simulation Techniques for Evaluating Smart Logistics Solutions for Sustainable Urban Distribution’, Procedia Engineering (178), pp. 569 – 578.
Lagorio, A., Pinto, R. and Golini, R. (2016) ‘Research in urban logistics: a systematic literature review’, International Journal of Physical Distribution & Logistics Management, 46(10), pp. 908–931.
lametro.fr. (2017) Retrieved from Grenoble-Alpes Métropole: Qualité de l'air: http://www.lametro.fr/460-qualite-air-pollution-grenoble.htm. Date of access: 10 April 2017
Leonardi, J., Browne, M. and Allen, J. (2012) ‘Before-after assessment of a logistics trial with clean urban freight vehicles: a case study in London’, Procedia - Social and Behavioral Sciences, 39, pp. 146–157.
Mancini, S. (2013) Multi-Echelon Distribution Systems in City Logistics. European Transport / Trasporti Europei, 54.
Ombuki-Berman, B., & Hanshar, F. (2009) Using Genetic Algorithms for Multi-depot Vehicle Routing. In F.Pereira, & J. Tavares, Bio-inspired Algorithms for the Vehicle Routing Problem (pp. 77-99). Berlin Heidelberg: Springer-Verlag.
Prodhon, C., & Prins, C. (2014) A survey of recent research on location-routing problems. European Journal of Operational Research 238, pp. 1-17.
Raimbault, N., Andriankaja, D. and Paffoni, E. (2012) ‘Understanding the Diversity of Logistics Facilities in the Paris Region’, Procedia - Social and Behavioral Sciences, 39, pp. 543–555.
Rao, C., Goh, M., Zhao, Y. and Zheng, J. (2015) ‘Location selection of city logistics centers under sustainability’, Transportation Research Part D, 36, pp. 29–44.
Reiter, K., Wrighton, S. and Rzewnicki, R. (2013) Potential to shift goods transport from cars to bicycles in European cities. Cyclelogistics Moving Europe forward.
Rockström, B. J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N. and Joachim, H. (2017) ‘A roadmap for rapid decarbonization’, Sciene, 355(6331).
Schenk, M., Assmann, T. and Behrendt, F. (2017) ‘Intelligente Lastenradlogistik’, in Jahrbuch Logistik 2017.
Schliwa, G., Armitage, R., Aziz, S., Evans, J. and Rhoades, J. (2015) ‘Sustainable city logistics — Making cargo cycles viable for urban freight transport’, Research in Transportation Business & Management, 15, pp. 50–57.
Staricco, L. and Vitale Brovarone, E. (2016) ‘The spatial dimension of cycle logistics’, TEMA, 9(2), pp. 173–190.
United Nations (2015) ‘Adoption of the Paris Agreement’, Conference of the Parties on its twenty-first session.
ups.com. (2017) Packing and Supplies: Dimensional Weight: https://www.ups.com/content/ch/en/resources/ship/packaging/dim_weight.html. Date of access: 10 April 2017
Vigo, D. (1996) A heuristic algorithm for the Asymmetric Capacitated Vehicle Routing Problem. European Journal of Operational Research, 89, pp. 108-126.
VNF (2015) VNF Cargo. Available at: http://www.vnf.fr/enewsletter_int/logistique_fille02.php?article=MTQ4 Date of access: 22 December 2015.
Weber, A., Chiadò, P. and Bruening, M. (2012) Test site final report - Berlin. citylog D5.
Zsolt, K. (2017) ‘Hajtás-Pajtás’, in European Cycle Logistics Conference (ECLF 2017). Vienna.

ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY OF A LARGE-SCALE RETAIL STORE

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ABSTRACT
This study investigates the issue of sustainability evaluation in a large-scale retail store (RS), which carries out four main different processes, i.e. Receiving, Backroom storage, Sales area management and Reverse logistics. A computational model is developed under Microsoft Excel™ to assess the costs and the CO_2 emissions of the RS. The application of the model is presented for a reference process (i.e. the Receiving process), while for the remaining processes, we present and discuss only the main results obtained. We found that the highest environmental impact and total cost are due to the Sales area management process, while Reverse logistics contributes to the total cost to a limited extent. The results obtained can provide useful guidelines for RS managers when pondering the optimization of sustainability.

Keywords: sustainability, large-scale retail store, case study, economic and environmental assessment.

1. INTRODUCTION

The term "sustainability" is derived from the Latin verb *sustinere*, composed of *tenere* (to hold), and *sub* (up). It has been used since 1980s referring to human sustainability and has resulted in the most widely quoted definition of sustainable development, which, according to the World Commission on Environment and Development (1987), is "the development that meets the needs of the present generations, without compromising the ability of the future generations to meet their own needs". Sustainable development is widely accepted to include economic development, social and human development, and environmental and ecological health (Goldman and Gorham, 2006).

Logistics and distribution activities are essential for sustaining our daily lives. However, from an environmental point of view, such activities could have a relevant impact, ranging from emissions into the environment, to the consumption of resources, up to the product's end-of-life (Rebitzer et al. 2004). Moreover, logistics systems are likely to generate undesired 'by-products', such as inefficient (or excessive) use of fossil burning fuels or CO_2 emissions (Kim et al. 2010).

From an economic perspective, the cost of logistics and distribution can also be relevant, accounting for approximately 10% of the gross domestic product of industrialized countries (World Economic Forum 2013). The relevant cost and environmental impact fuel a lot of discussions about the efficiency and effectiveness of logistics activities (Borgström 2005; Fugate, Mentzer, and Stank 2010). In response to the above issues, companies are increasingly seeking solutions to reduce their logistic cost and increase sustainability. In some industrial contexts, such as the fashion industry or the food one, the economic and environmental issues are particularly relevant and have been evaluated by the researchers (e.g., Bigliardi and Bottani 2012 or Manfredi and Vignali 2014).

A context that has potential to play a relevant role for sustainability is the retailing field (Erol et al. 2009) and increasingly, sustainability is considered a core value and practice in retailing (Wiese et al. 2012). Pressure on retailers to integrate sustainability into their business practices is also increasing (European Environment Agency 2010). In addition, as retailers are at the crossroads between producers and consumers in a supply chain, their role in promoting sustainable production and logistics is crucial (Bonini and Oppenheim 2008; Jones, Comfort, and Hillier 2009).

In line with the considerations above, in this paper we focus on the evaluation of the economic and environmental sustainability of a particular player in the retailing field, i.e. a large-scale retail store (RS). To be more precise, we illustrate the evaluation of the total cost and CO_2 emissions of the RS by means of an analytic model developed under Microsoft Excel™. The model takes into account the key logistics processes of the RS, although, for the sake of brevity, the details of the computational procedure and of its application are provided only for a reference process (i.e. the Receiving process).

The remainder of the paper is organized as follows. The next section describes the methodology adopted to develop the model. The application of the model to the case of a large-scale RS is described in section 3, together with the results obtained. Discussion, implications, limitations and future research directions are proposed in section 4.

2. METHODOLOGY

2.1. Retail store processes

This study takes into account the key supply chain processes of large-scale RS, i.e. Receiving, Backroom storage, Sales area management and Reverse logistics.

The Receiving process is the first process encountered by an item arriving at the RS (Rouwenhorst, et al. 2000). The receiving activity includes the unloading of products from the transport carrier, updating the inventory record, inspection to find if there is any quantity or quality inconsistency. Transfer and put away involves the transfer of incoming products to storage locations (De Koster, Le-Duc, and Roodbergen 2007). Storage is concerned with the organization of goods held in the warehouse in order to achieve high space utilization and facilitate efficient material handling (Gu, Goetschalckx, and McGinnis 2007). The sales area of a RS is the space on which both the manpower and the consumers stand and move. It is energy intensive and includes ventilation and air conditioning (HVAC) systems, heating and cooling set points and schedules, lighting types, levels and schedules and refrigeration plants (Parker et al. 2017). The return flow of food products is a typical problem of reverse logistics and concerns distribution activities involved in food-packaging returns, recycling/recovery, reuse and/or disposal. Reverse logistics activities are often supported by specific facilities, typically collection centres, where products are recovered, repaired or recycled. Therefore, the network structure needs to be extended with transportation links for return flows from customer locations to collection sites (Fancello et al. 2017).

2.2. Model overview

An evaluation model was developed under Microsoft Excel™ to support the assessment of the economic and environmental sustainability of the RS. This model consists of four spreadsheets. Each of them reproduces one of the RS processes described in the previous section, and computes the relating economic and environmental impact. For the sake of brevity, in the following we will illustrate in detail the application of the model for a representative RS process (i.e. the Receiving process), with the aim to detail the computational steps for the assessment of both the economic and environmental sustainability. For the remaining RS processes, we will present the results obtained from the application of the model, omitting the detailed steps. The notation used in the analysis (limited to the process considered) is shown in Table 1.

Table 1: Nomenclature

Symbol	Description	Unit of measurement
Subscripts		
R	Receiving	-
f	Fresh	-
d	dry	
tot	Total	-
$I,T\text{-}Q;D$	Identification, type and quantity, documents	-
u	Unitary	-
Receiving parameters		
$n_{(pallets/day),R}$	Amount of pallets received	[pallets/day]
$C_{u,litre}$	Fuel cost	[€/l]
D_{litre}	Distance per litre	[km/l]
$n_{(pallets/truck),R}$	Amount of pallets that can be loaded on a truck during receiving	[pallets/truck]
$N_{days/year}$	Working days per year	[days]
D_a	Average distance from retail stores to Distribution Centre	[km]
$n_{(truck/year),R}$	Amount of trucks per year in Receiving Process	[trucks/year]
$C_{(t,tot),R}$	Total cost of transport in Receiving Process	[€/year]
$FC_{truck,f}$, $FC_{truck,d}$	Fuel consumption for a refrigerated truck in different range of temperature	[l/h]
FC_f, FC_d	Annual fuel consumption for fresh/dry products	[litres/year]
$C_{E,f}$, $C_{E,d}$	Cost of energy for transport of fresh/dry products	[€/year]
$C_{m,u}$	Average hourly cost of manpower	[€/h]
$C_{m,R}$	Cost of manpower per year in Receiving	[€/year]
$ER_{I,R}$, $ER_{T\text{-}Q,R}$	Error made in products receiving (identification, type and quantity)	[case/day]
$ER_{D,R}$	Error made in products receiving (documents)	[orders/month]
$T_{(ER,I),R}$, $T_{(ER,T\text{-}Q),R}$	Time required to amend identification/type and quantity errors	[min/case]
$T_{(ER,D),R}$	Time required to amend documents errors	[min/order]
$C_{(ER,I),R}$, $C_{(ER,D),R}$, $C_{(ER,T\text{-}Q),R}$	Cost to amend identification/documents/type and documents errors	[€/year]
$C_{ER,R}$	Total cost to amend errors in received pallets	[€/year]
$C_{tot,R}$	Total cost of the Receiving process	[€/year]

E_f, E_d	Energy absorbed by a truck to transport fresh/dry products	[kWh/year]
I_f, I_d	Environmental impact of fresh/dry products transport	[tonCO_2/year]
$I_{truck,R}$	Environmental impact of a full load truck	[tonCO_2/year]
I_{truck}	Environmental impact of a truck per km	[tonCO_2/km]
$I_{tot,R}$	Total environmental impact	[tonCO_2/year]
t_{trip}	Amount of hours per trip	[h/trip]
$n_{employees,R}$	Number of employees in the Receiving process	-
$h_{day,R}$	Hours per working day in the Receiving process	[h/day]
d_{diesel}	Density of diesel fuel at normal environmental condition	[kg/m^3]
$\%T_i$	Percentage of ignition time of the refrigerator unit of the truck	-

2.3. Preliminary assumptions

The model developed is based on some assumptions, which have emerged both from the analysis of the literature available and from the suggestions provided by the managers of some RSs involved in the study (see the details in section 3.1). They are listed and described in the following.

1. Since the products handled at the RS are of different nature, they have been grouped into two categories, i.e. “fresh” and “dry” products. The amount of fresh products accounts for 15% of the total volume of items handled at the RS, while the percentage of dry ones accounts for 85%;
2. The disposal process for the expired products is typically at the expense of the distribution centre (DC); therefore, it is not considered in this analysis;
3. The present work does not take into account the process of checking the returned products, to identify a possible alternative use (instead of the disposal option). Indeed, this process is typically managed by means of specific agreements between the RS and its suppliers.

3. MODEL APPLICATION

In the following sections, we describe the application of the computational model to a reference process, taken as a case study.

3.1. Input data

The model developed takes several data as input. As far as the numerical values of the input data are concerned, they have been obtained from both a data collection phase and from a careful bibliographic analysis was carried out with the support of the Scopus database (www.scopus.com). To be more precise, a sample of four RSs of different size, i.e. two hypermarkets and two supermarkets, was investigated to collect the most relevant data relating to the supply chain processes under examination. These data were then averaged on the sample of RSs considered. Some previous publications (Bottani and Rizzi 2008; Bottani and Montanari 2010) and other available sources were also used to retrieve the remaining input data. The full list of input data relevant to the Receiving process is provided in Table 2.

Table 2: Input Data for the Receiving Process

Parameter	Numerical value	Measurement unit	Source
$n_{(pallets/day),R}$	168	[pallets/day]	(Bottani and Montanari 2010)
$C_{u,litre}$	1.37	[€/l]	(Ministero dello Sviluppo Economico 2017)
D_{litre}	2.6	[km/l]	(Econoliberal 2012)
$n_{(pallets/truck),R}$	33	[pallets/truck]	calculated using the standard size of a Euro-pallet
$N_{days/year}$	320	[days]	(Bottani and Rizzi 2008)
D_a	103.67	[km]	(ECR Italy 2014)
$FC_{truck,f}$, $FC_{truck,d}$	0.75 (T°=[-25, +3]°C); 2.25 (T°=[+3, +25]°C)	[l/h]	(Tassou, De-Lille, and Lewis 2012)
t_{trip}	3	[h/trip]	Direct observation
$C_{m,u}$	13.17	[€/h]	(Unione Nazionale Cooperative Italiane 2015)
$n_{employees,R}$	5	-	Direct observation
$ER_{I,R}$	0.25	[case/day]	(Bottani and Rizzi 2008)
$ER_{D,R}$	13.8	[order/month]	(Bottani and Rizzi 2008)
$ER_{T-Q,R}$	13.8	[case/day]	(Bottani and Rizzi 2008)
$T_{(ER,I),R}$	7.5	[min/case]	(Bottani and Rizzi 2008)
$T_{(ER,D),R}$	50.6	[min/order]	(Bottani and Rizzi 2008)
$T_{(ER,T-Q),R}$	8.75	[min/case]	(Bottani and Rizzi 2008)

I_{truck}	6.22*10^-4	[tonCO$_2$/km]	(Ciccarello and Caserini 2011)
$h_{day,R}$	8	[h/day]	Direct observation
d_{diesel}	850	[kg/m^3]	(Wang and Economides 2009)
$\%T_i$	60%	-	Direct observation

3.2. Receiving process

In the following, we describe the computational procedure to quantify the costs and emissions arising from the management of Receiving process. As the analysis focuses more on transport activity, it is important to point out that the type of vehicles considered for deliveries to RS is a 33-pallet lorry (see Table 2).

3.2.1. Economic analysis

To compute the relevant costs of the Receiving process, the first step is to calculate the number of trucks per year required to deliver the products to the RS. This could be obtained starting from the amount of pallet received per day and the total amount of pallets loaded on a truck of given capacity.

$$n_{(truck/year),R} = \left\lceil \frac{n_{(pallets/day),R}}{n_{(pallets/truck),R}} \right\rceil * N_{days/year} \quad (1)$$

The total cost of transport for Receiving activities, $C_{(t,tot),R}$ can be computed as follows:

$$C_{(t,tot),R} = \frac{C_{u,litre}}{D_{litre}} * D_a * n_{(truck/year),R} \quad (2)$$

Taking into account assumption #1 in section 2.3, such a cost can be shared among the different categories of products treated, i.e. 15% for fresh products and the remaining 85% for dry ones.

Further economic impacts relating to the receiving activities are caused by the fuel consumption. Because the transport of fresh product requires refrigerated trucks, the fuel consumption should be computed separately for dry and fresh products, as follows:

$$FC_d = FC_{truck,d} * t_{trip} * n_{(truck/year),R} * 0.85 \quad (3)$$

$$FC_f = FC_{truck,f} * t_{trip} * \%T_i * n_{(truck/year),R} * 0.15 \quad (4)$$

Consequently, the impacts account for:

$$C_{E,d} = C_{u,litre} * FC_d \quad (5)$$

$$C_{E,f} = C_{u,litre} * FC_f \quad (6)$$

Another cost component is the cost of employees who carry out receiving operations. Taking into account the number of employees serving this process, the following equation can be used:

$$C_{m,R} = C_{m,u} * h_{day,R} * N_{days/year} * n_{employees,R} \quad (7)$$

During receiving, employees can also work to amend possible errors in the pallets received (documents, product type and quantity, identification). The relating cost was computed for each type of errors, according to the following equations:

$$C_{(ER,T-Q),R} = \frac{T_{(ER,T-Q),R}}{60} * C_{m,u} * ER_{T-Q,R} * N_{days/year} \quad (8)$$

$$C_{(ER,D),R} = \frac{T_{(ER,D),R}}{60} * C_{m,u} * ER_{D,R} * 12 \quad (9)$$

$$C_{(ER,I),R} = \frac{T_{(ER,I),R}}{60} * C_{m,u} * ER_{I,R} * N_{days/year} \quad (10)$$

The total economic impact caused by the error management in Receiving operations accounts for:

$$C_{ER,R} = C_{(ER,T-Q),R} + C_{(ER,D),R} + C_{(ER,I),R} \quad (11)$$

Total economic impact the receiving process at the RS ($C_{tot,R}$) can finally be computed by adding up the contributions listed above:

$$C_{tot,R} = C_{(t,tot),R} + C_{E,d} + C_{E,f} + C_{m,R} + C_{ER,R} \quad (12)$$

3.2.2. Environmental analysis

Besides the economic performance, the environmental sustainability of the Receiving process was evaluated taking into account different contributions relating the transport phase, namely: the environmental impact of fresh and dry products transport (I_f;I_d) and the amount of CO_2 emissions of a full load truck ($I_{truck,R}$). To calculate I_d, the energy absorbed by truck for dry transport (E_d) should be first estimated.

Using the following conversion factors:

$$1\ litre = 1\ dm^3 = 0.001\ m^3 \quad (13)$$

$1\ tonCO_2 = 42.877\ GJ$ (Minambiente 2016) (14)

$$1\ kWh = 3.6 * 10^6\ J \quad (15)$$

the energy absorbed by a truck can be estimated as follows:

$$E_d = \frac{FC_d * 0.001 * d_{diesel} * 42.877}{3.6 * 10^6} \quad (16)$$

Using again a conversion (Emilia Romagna 2015), i.e.:

$$1kWh = 2.642 * 10^{-4}\ tonCO_2 \quad (17)$$

the environmental contribution for the transport of dry products can be calculated as follows:

$$I_d = E_d * 2.642 * 10^{-4} \quad (18)$$

Following a similar approach, the environmental impact of the fresh products transport (I_f) was computed as follows:

$$E_f = \frac{FC_f * 0.001 * d_{diesel} * 42.877}{3.6 * 10^6} \quad (19)$$

$$I_f = E_f * 2.642 * 10^{-4} \quad (20)$$

The environmental impact of all trucks used to collect the pallets from the DC to the RS is finally obtained by adding up the contribution of each truck and taking into account the transport distance, according to the following formula:

$$I_{truck,R} = I_{truck} * D_a * n_{(truck/year),R} \quad (21)$$

Finally, the total environmental impact was derived by adding up the contributions listed above:

$$I_{tot,R} = I_d + I_f + I_{truck,R} \quad (22)$$

3.2.3. Results

We now report the main results of the analysis for the receiving process, in terms of the economic contribute (purple highlighting) and the environmental (light blue highlighting) one, with the purpose of evaluating the sustainability of RS. The results, including both the absolute value and the percentage sharing of each component, are shown in table 3.

Table 3: Costs and Emissions for the Receiving Process

Receiving				
Activities	**Costs [€/year]**	**%**	**Emissions [tonCO_2/year]**	**%**
Manpower	168,576.00	58.03	-	-
Transport	104,878.77	36.10	123.80	90.54
Fuel consumption - dry products	5,030.64	1.73	9.82	7.18
Fuel consumption - fresh products	1,597.97	0.55	3.12	2.28
Error management - type and quantity	8,450.75	2.91	-	-
Error management - documents	1,833.51	0.63	-	-
Error management – product identification	131.70	0.05	-	-
Total	**290,499.34**	**100.00**	**136.74**	**100.00**

As shown in Table 3, the activity that entails the greatest cost in the Receiving process is the manpower (168,576.00 €/year), which accounts for 58.03% of the total cost of the process. In addition, the transport activity significantly affects the environmental performance of the process (123.80 tonCO_2/year), and its economic impact cannot be neglected as well (36.10%).

3.3. Backroom storage

In a real RS, the storage area is typically used only for handling and storage of dry products. Conversely, fresh products are rarely managed in the RS backroom, being typically received and located directly on the store shelves. The main results obtained by applying the evaluation model to the Backroom storage are shown in the Table 4, for both the economic and environmental aspects of sustainability.

Table 4: Costs and Emissions for the Backroom Storage

Backroom Storage				
Activities	**Costs [€/year]**	**%**	**Emissions [tonCO_2/year]**	**%**
Manpower	168,576.00	49.77	-	-
Inventory	20,000.00	5.90	-	-
Maintenance of fork lift trucks	939.72	0.28	0.77	5.05
Sale losses	722.93	0.21	-	-
General and replenishment operations	148,504.92	43.84	-	-
Energy consumption of the warehouse	-	-	14.50	94.95
Total	**338,743.58**	**100.00**	**15.28**	**100.00**

As shown in Table 4, the activities that generates the highest cost in the Backroom storage are the manpower management (168,576.00 €/year) and the replenishment operations (148,504.92 €/year); such activities account for 49.77% and 43.84% of the total cost of the process, respectively. From an environmental perspective, CO_2 emissions are mainly due to energy consumption of the warehouse (14.50 tonCO_2/year).

3.4. Sales area management

Sales area management includes all processes aimed at selling the finished product to the end user. Table 5 provides the results of economic and environmental assessment of this process.

Table 5: Costs and Emissions for the Sales Area Management

Sales Area				
Activities	**Costs [€/year]**	**%**	**Emissions [tonCO_2/year]**	**%**
Manpower	505,728.00	15.75	-	-
Replenishment operations	17,026.18	0.53	-	-
Sale losses	111,412.24	3.47	-	-
Inventory	1,890,000.00	58.87	-	-
Energy consumption related to refrigeration plants	140,987.70	4.39	115.68	12.67
HVAC consumption	281,505.44	8.77	230.97	25.29

related to sales area				
H_2O consumption related to sales area	10,714.91	0.33	8.79	0.96
Lighting of the sales area	253,173.63	7.89	207.73	22.75
Emissions of HFC gas	-	-	350.00	38.33
Total	**3,210,548.10**	**100.00**	**913.17**	**100.00**

As shown in Table 5, the most onerous cost component is the cost of inventory at the RS (1,890,000.00 €/year), followed by the manpower cost (505,728.00 €/year). The most relevant emissions of this process are due to HFC gas for refrigeration (38.33%), HVAC (25.29%) and lighting (22.75%).

3.5. Reverse logistics

Reverse logistics activities, i.e. the return flow from the RS to the DC, are assumed to be performed using *ad hoc* shipments, carried out by a small truck that retrieves the expired product at RS daily and ships it back to the DC for disposal. The distinction between dry and fresh products (as in Receiving Process) is not made. Indeed, as the returned product is typically expired, preserving its organoleptic properties by means of a refrigerated transport is not strictly necessary. The cost of the Reverse logistics process covers mainly the transport cost, as the disposal cost is typically ascribed to the supplier, according to the assumptions made. Table 6 lists the main results for the economic and environmental aspects of this process.

Table 6: Costs and Emissions of the Reverse Logistics Process

Reverse Logistics				
Activities	**Costs [€/year]**	**%**	**Emissions [tonCO_2/year]**	**%**
Transport	17,480.79	94.66	8.03	80.65
Fuel consumption	986.40	5.34	1.93	19.35
Total	**18,466.19**	**100.00**	**9.95**	**100.00**

4. DISCUSSIONS AND CONCLUSIONS

In this paper, we have evaluated the economic and environmental sustainability of a large-scale RS. The analysis takes into account the key supply chain processes of the RS, i.e. Receiving, Backroom storage, Sales area management and Reverse logistics. In particular, we described the application of a computational model, developed in Microsoft Excel™ to evaluate the cost and CO_2 emissions of the RS processes, to a reference process, i.e. the Receiving process. For this process, which is taken as a case study, we have detailed the equations implemented in the model to carry out the computation; for the remaining processes, the detailed computational procedure is omitted, for brevity, and only the main results are presented.

The comparison of the economic outcomes obtained for the four RS processes analysed is shown in Figure 1.

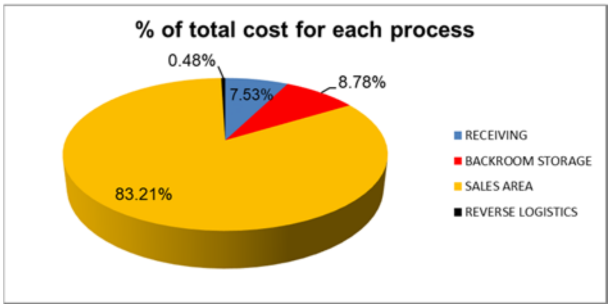

Figure 1: Comparison of the costs of the RS processes

As can be seen from Figure 1, the process with the highest cost is the Sales area management (83.21%), followed by the Backroom storage and Receiving processes, which account for 8.78% and 7.53% of the total cost, respectively. The total cost of the Reverse logistics process is almost null, mainly because of the assumptions made in the evaluation, that the RS does not incur in the cost of the returned products and disposal process.

The comparison of the environmental emissions of the four different processes analysed is shown in Figure 2.

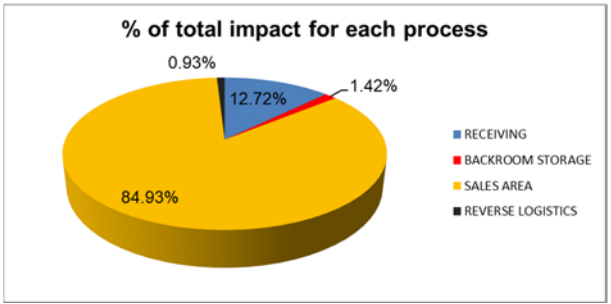

Figure 2: Comparison of the emissions for the RS processes.

As can be seen from Figure 2, the process with the highest CO_2 emission (in percentage) is the Sales area management (84.93%), followed by the Receiving process (12.72%). For the Backroom storage and Reverse logistics processes, the environmental impact is significantly lower than in the remaining processes (1.42% and 0.93% respectively).

The results of the study provide an idea of the total cost and environmental impact of a large-scale RS. Interesting scientific and practical contributions are given: indeed, the outcomes can be used by RS managers to identify the processes on which to concentrate with the aim to reduce the economic and environmental impacts. Moreover, the study also indicates the specific activity or component on which to intervene to remove any inefficiencies, thus optimizing sustainability.

From a technical perspective, some limitations of the analysis should be mentioned. Specifically, the present work does not take into account the processes of disposal or check of the returned products. This could be a future adjustment to be made to the model, in the attempt to evaluate the economic and environmental performance of the whole retail supply chain.

Also, starting from this work, several future research directions could be undertaken. The study developed could be used to analyse RS of different size, with the purpose of evaluating whether the economic and environmental performance may be different depending on the size of the store. Moreover, the choice of the processes could be modified, including further activities in the evaluation.

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REFERENCES

Bigliardi B., Bottani E., 2012. Green Manufacturing practies in the fashion supply chain: lessons from Italian case studies. Internation Journal of Agile Systems and Management, 5 (1), 4-28.

Bonini S., Oppenheim J., 2008. Cultivating the green consumer. Standford Social Innovation Review, 6 (4), 56-61.

Borgstrom B., 2005. Exploring efficiency and effectiveness in the suplly chain: a conceptual analysis. Proceedings of the 21st IMP-Conference, pp. 1-13. September 1-3, Rotterdam (Netherlands).

Bottani E., Montanari R., 2010. Supply chain design and cost analysis through simulation. International Journal of Production Research, 48 (10), 2859-2886.

Bottani E., Rizzi A., 2008. Economical assessment of the impact of RFID technology and EPC system on the fast moving consumer goods supply chain. International Journal of Production Economics, 112 (2), 548-569.

Ciccarello A., 2011. Analisi dei fattori di emissione di CO2 da traffico stradale. Politecnico di Milano.

De Koster R., Le-Duc T., Roodbergen K., 2007. Design and control of warehouse order picking: a literature review. European Journal of Operational Research, 182 (2), 481-501.

Econoliberal, 2012. Econoliberal. Available from: http://www.econoliberal.it/2012/02/dietro-le-quinte-gli-autotrasporti.html [accessed 6 June 2017]

ECR Italy, 2014. La logistica per la creazione di valore nella filiera di largo consumo. Available from: https://gs1it.org/content/public/46/e6/46e65baf-6bbf-4a01-a304-929a7d6899b3/logistica_creazione_valore_filiera.pdf [accessed 6 June 2017]

Emilia Romagna, 2015. Indicazioni metodologiche per l'applicazione dei fattori di conversione al metodo di calcolo di cui alla DGR 967/2015 e alla DGR 1275/2015. Available from: http://energia.regione.emilia-romagna.it/entra-in-regione/norme-e-atti-amministrativi/certificazione-energetica/certificazione-energetica/DOC_INDIRIZZO_fattoridiconversione_2.pdf [accessed 27 June 2017]

Erol I., Cakar N., Erel D., Sari R., 2009. Sustainability in the Turkish retailing industry. Sustainable development, 17 (1), 49-67.

European Environment Agency, 2010. Consumption and the environment: SOER 2010 thematic assessment. Available from: https://www.eea.europa.eu/soer/europe/consumption-and-environment [accessed 11 July 2017]

Fancello G., Mola F., Frigau L., Serra P., Mancini S., Fadda P., 2017. A new management scheme to support reverse logistics processes in the agrifood distribution sector. Transportation Research Procedia, 25, 695-715.

Fugate B., Mentzer J., Stank T., 2010. Logistics performance: efficiency, effectiveness, and differentiation. Journal of Business Logistics, 31 (1), 43-62.

Goldman T., Gorham R., 2006. Sustainable urban transport: four innovative directions. Technology in Society, 28 (1-2), 261-273.

Gu J., Goetschalckx M., McGinnis L., 2007. Research on warehouse operation: a comprehensive review. European Journal of Operational Research, 177 (1), 1-21.

Jones P., Comfort D., Hillier D., 2009. Marketing sustainable consumption within stores: a case study of the UK's leading food retails. Sustainability, 1 (4), 815-826.

Kim S., Yoon S., Chae S., Park S., 2010. Economic and environmental optimization of a multi-site utility network for an industrial complex. Journal of Environmental Management, 91 (3), 690-705.

Manfredi M., Vignali G., 2014. Life cycle assessment of a packaged tomato puree: a comparison of environmental impacts produced by different life cycle phases. Journal of Cleaner Production, 73, 275-284.

Minambiente, 2016. Tabella parametri standard nazionali. Available from: http://www.minambiente.it/sites/default/files/archivio/allegati/emission_trading/Tabella_coefficienti_standard_nazionali_2013_2015_v1.pdf [accessed 27 June 2017]

Ministero dello Sviluppo Economico, 2017. Ministero dello Sviluppo Economico, Statistiche dell'Energia. Available from: http://dgsaie.mise.gov.it/dgerm/bphitalia.asp?txtAnno=2017&txtMese=6&txtGiorno=5 [accessed 6 June 2017]

Parker J., Glew D., Fletcher M., Thomas F., Gorse C., 2017. Accounting for refrigeration heat exchange in energy performance simulations of large food retail buildings. Building Service Engineering Research and Technology, 38 (3), 253-268.
Rebitzer G., Ekvall T., Frischknecht R., Hunkeler D., Norris G., Rydberg T., Pennington D., 2004. Life cycle assessment - Part 1: Framework, goal and scope definition, inventory analysis, and applications. Environment International, 30, 701-720.
Rouwenhorst B., Reuter B., Stockrahm V., Van Houtum G., Mantel R., Zijm W., 2000. Warehouse design and control: framework and literature review. European Journal of Operational Research, 122 (3), 515-533.
Tassou S., De-Lille G., Lewis J., 2012. Food transport refrigeration. Centre for Energy and Built Environment Research, School of Engineering and Design, Brunel University. Available from: http://www.grimsby.ac.uk/documents/defra/trns-refrigeenergy.pdf [accessed 6 June 2017]
Unione Nazionale Cooperative Italiane, 2015. Contratto collettivo nazionale di lavoro per i dipendenti e i soci lavoratori delle cooperative. Available from: http://www.anpit.it/wp-content/uploads/2015/07/CONTRATTO-COOPERATIVE.pdf [accessed 7 July 2017]
Wang X. and Economides M., 2009. Advanced natural gas engineering. 1st ed. Houston: Gulf Publishing Company.
Wiese A., Kellner J., Lietke B., Toporowski W., Zielke S., 2012. Sustainability in retailing - a summative content analysis. International Journal of Retail & Distribution Management, 40 (4), 318-335.
World Commission on Environment and Development, 1987. Our Common Future. Brundtland Report, University Press.
World Economic Forum, 2013. Enabling trade valuing growth opportunities. Available from: http://www3.weforum.org/docs/WEF_SCT_EnablingTrade_Report_2013.pdf [accessed 11 July 2017]

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SIMULATION OF AUTONOMOUS SYSTEMS COLLABORATING IN INDUSTIAL PLANTS FOR MULTIPLE TASKS

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ABSTRACT

The autonomous systems are continuously extending their application fields and current advances in sensors and controls are enabling the possibility to operate also inside buildings and industrial plants. These new capabilities introduce challenges to be addressed in order to carry out new tasks and missions. This paper proposes advances in Modeling, interoperable Simulation and Serious Games devoted to support researches supporting autonomous system operations within Industrial Facilities.

Keywords: Autonomous Systems, Safety, Industrial Plants, Security, Modeling and Simulation

1 INTRODUCTION

Industrial Plants represent a complex mission environments considering the characteristics of their processes as well as the high density in such facilities of equipment, machines and components. Classical examples are represented by Power & Chemical Plants, On-Shore & Off-Shore Platforms, Water Treatment Facilities and large industrial Area. These examples are characterized by several heavy constraints related to safety and security, indeed they often are critical infrastructures and, in case of accident, could generate dangers for human life over wide areas (Merabiti et al. 2011). In this context, most cases are related to the release of toxic compounds into the atmosphere and to the onset of critical concentration of gaseous flammable mixtures (Fabiano et al. 2015; Reverberi et al. 2016). Obviously the urbanization currently is further stressing these aspects by encompassing within large towns the industrial complexes. In case of accidents, many of these facilities result immediately pretty dangerous for humans and requires to address specific tasks respect industrial processes (e.g. shut down machines and apply safety procedures) to verify the possibility of accident escalation, addressing a proper emergency planning and actions for injured personnel such as triage (Palazzi et al., 2017). Due to these reasons the use of autonomous systems to act as “first responders” assessing the situation and to support relief operations are very promising especially if integrated with legacy systems already available on the field (Bruzzone et al. 2016b); up to now these activities have been developed and tested mostly in outdoor environment for large disasters such as earthquakes and forest fires (Apvrille et al. 2015). It is very interesting to develop similar capabilities to operate within Industrial Plants, even if the structures, obstacles as well as the very intensive dynamics of the accident could make very challenging for the robots to operate within this environment; for instance in the case of Fukushima accident the robots sent inside the plant had severe damages making them unable to return back and finalize most of their missions (McCurry 2017). It is evident the necessity to develop virtual experimental frameworks to investigate and test new solutions in these scenarios by using dynamic Modeling and Simulation (McLeod 1968; Massei et al. 2016). Indeed, this paper proposes a simulation framework able to support this analysis and a case study related to a plant accident where different robotic systems, operating over multiple domains, collaborate by carrying out multiple tasks autonomously (Veil & Veloso 2003; Ferrandez et al.2013). The example is very useful for validating the potential of the modeling approach adopted and the issues about Composability of mixed solutions. In this context, it is important to include innovative techniques of Artificial Intelligence such as Intelligent Agents and Swarm Intelligence (Wooldridge 1995; Bruzzone et al. 2011; Stodola 2014). Currently the authors are further developing this researches by focusing on the development of a new flexible UGV able to operate inside big industrial plants with multiple missions and to interoperate with other systems.

2 AUTONOMOUS SYSTEMS AND MODELS FOR INDUSTRIAL PLANTS

In facts, in order to benefits from the new capabilities of the autonomous systems and to support the development of innovative solutions able to address these new missions, in a feasible and sustainable way, it is required to carried out extensive R&D activities. In facts these researches could drastically benefit from accessing synthetic environments devoted to virtually test the new engineering solutions as well as to measure their performance, capabilities and reliability levels. It is evident that these scenarios have an high degree of complexity related to the industrial plant nature itself, but also to the high number of stochastic factors (e.g. malfunctions, plant process and accident dynamics, boundary conditions, human presence, etc.). Based on these elements and due to the necessity to carry out extensive experimentation, the use of M&S (Modeling and Simulation) emerges as most promising investigation methodology (Bruzzone et al. 2016a).

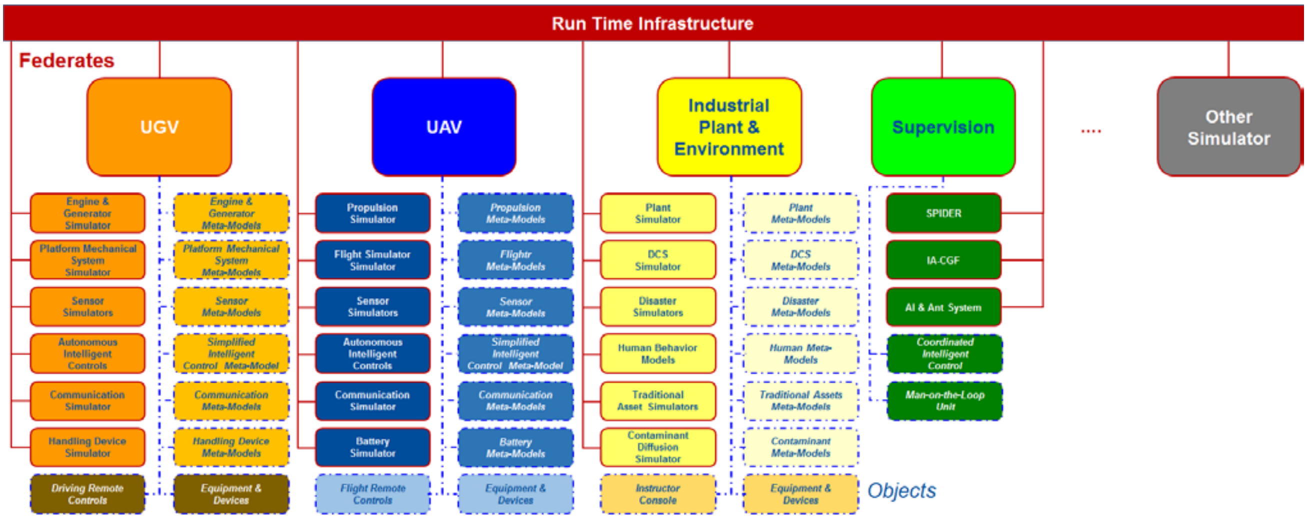

Fig.1- Example of Federation including Simulators and Objects

In industrial plant the use of UAV (Unmanned Aerial Vehicles) have been studied in several case with special attention to Nuclear Plants in critical conditions (Sugisaka 2011; Moranduzzo et al. 2014). Recently indoor operations as well as missions within GPS-denied areas have been investigated to carry out inspections, for instance within Boilers of Power Plants (Nikolic et al. 2013). In addition UAS (Unmanned Aerial Systems) have been applied also to address performance measures such as in the case of Photovoltaic Plants (Grimaccia et al. 2015). In reference to UGV (Unmanned Ground Vehicles) there are expectations to further developments in industry based on technology advances (Tilbury et al. 2011). From this point of view the experiences in Oil & Gas both in on-shore and off-shore is pretty promising respect use of UxV (Unmanned multi domain Vehicles) in terms of inspections, controls, etc (Shukla & Karki 2016). In facts Simulation Team developed examples of these applications combining UAV, USV and AUV for Off-Shore Platforms and On-Shore Industrial Complexes (Bruzzone et al. 2016b).

3 MULTIPLE MISSIONS FOR AUTONOMOUS SYSTEMS IN INDUSTRIAL PLANTS

In facts, the large investments required for developing new solutions based on innovative autonomous system for safety and emergency management in industrial plants need to be carried out in a sustainable way; so it is strongly recommended to develop and tailor these UxV for being able to carry out multiple missions devoted to cover regular industrial operations as well as to complete critical tasks during crisis (Bruzzone et al.2016a). In facts, often it is not possible to adopt and install industrially the solutions based on current state of art advances, such as last DARPA competitions, also to the pretty high costs related with these developments (Tether 2006; Guizzo et al.2015; Lim et al. 2015). In facts, it is evident that the impressive capabilities proposed by the very advanced KAIST robot, are still not able to satisfy industrial requirements not only in terms of costs, but also of speed and responsiveness for most accidents that are characterized by very fast dynamics (Ackerman et al. 2015). Therefore in real industrial plants, usually, the generalization needed for addressing emergency management could be quite severely restricted due to specific context, making it possible to develop with today affordable technologies much more lean solutions (e.g. simple positioning, pre-defined access methods, redesign of some element of the plant for autonomous system use, etc.); this consideration is confirmed by recent researches in this sector (Ross et al.2006; Bruzzone et al. 2016b)

In facts, several industrial plants are plenty of tasks and activities currently carried out by humans in dangerous frameworks (e.g. controls on confined spaces and on tall chimneys) where autonomous systems could be very useful for improving safety; these autonomous systems obviously have to address similar challenges to that ones to be used for emergency management or during accidents (e.g. moving around, conducting measurements or inspections, obstacle avoidance, etc.); so it is evident the importance to develop solutions able to address multiple tasks to increase utilization and return of investments for these new systems. In facts today, it is possible to develop autonomous systems able to carry out multiple missions in this context: for instance monitoring the plant processes, inspecting symptoms of malfunctions, controlling environmental and operational parameters, relieving the presence of humans in dangerous areas and supporting security.

In this way these devices could increase efficiency, effectiveness and safety even during regular operations, so in case of accident they could be already operative on site for being used in emergency management and disaster relief. In addition to the aspects related to the Industrial use of these autonomous systems, it could be even considered the possibility to tune them to address security and defensive tasks in reference to critical infrastructure protection respect different kinds of threats (Bachmann et al.2014). In facts the increase of security issues along last years (e.g. terrorism, social instability, etc.) suggests that this aspect could provide a

significant improvement with marginal costs, while it could represent even an opportunity to obtain public support for dual use: vulnerability reduction of a critical infrastructure and improvements on safety for working condition within the plant (Pugh 2005; Brown et al.2006; Bruzzone et al.2016b).
However it is important to outline that UxVs need to be protected and operating within secure networks in order to avoid vulnerability from cyber attacks that could turn them into resources for threat networks (Rani et al. 2016).
In facts, this is a very good example of general use that sustain the diffusion of innovative solutions able to interact with legacy system and to reduce vulnerability and improve safety.

4 CHALLENGES OF INDUSTRIAL PLANTS FOR AUTONOMOUS SYSTEM

As anticipated industrial plants represent a very challenging environment to operate autonomous systems for several reasons; first of all many electromagnetic interferences and obstacles are present in plants; for instance inside there is often a very high density of suspended pipelines, cable trays, cables, wires; the industrial production usually requires high power installation generating intense electromagnetic field; in addition the dense metallic structures represent physical and electromagnetic challenges for autonomous systems. In addition to these element the mechanical, thermal and chemical processes related to the industrial production could represent additional challenges altering the perception of the sensor and their reliability (e.g. high irradiating sources, dust, etc.).
All these conditions affects drastically not only movement and regular visibility, but also IR spectrum and electromagnetic compatibility and communications as well as positioning system.
In facts, an UxV (Unmanned x-th domain Vehicle) usually requires to be able to use different sensors and data functions features to properly complete their missions (Stodola & Mazal 2010b) as well as to have an high degree of autonomy to continue to operate and collaborate with other autonomous entities in case of communication failure with centralized supervision system (Feddema et al. 2002; Tanner et al.2007b). In addition to these elements the presence of pipelines, tanks with flammable gases and liquids, as well high tension cables make this environment subject to dangers while moving autonomous systems or remotely piloted vehicles that could crash or hit sensitive parts; these considerations are especially true for process plants, therefore it is also important to keep in mind that the co-presence of humans in the areas provide other sources of risks in this joint operations.
In addition, operating within industrial plants to carry out monitoring activities during crucial moments (e.g. as response to an alarm) or for emergency management in case of accidents, introduce additional challenges to the UxV operations and it is very critical to identify the best configurations and solution to be put in place.

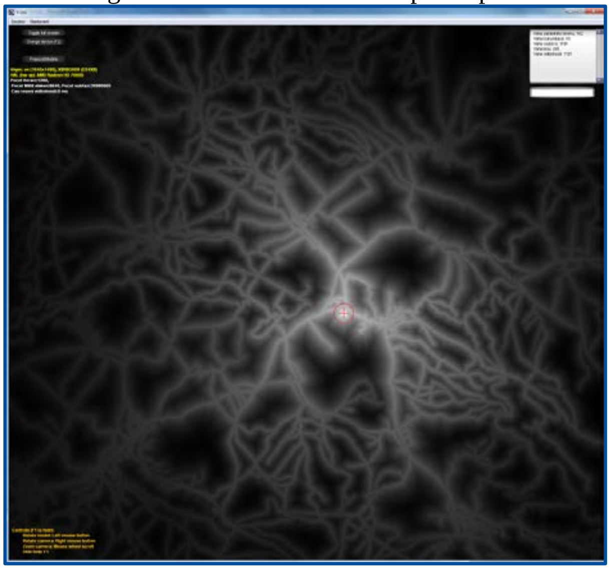

Fig.2- Path Optimality Map implementing multi criteria constraints: Initial Path Point within the Red Circle

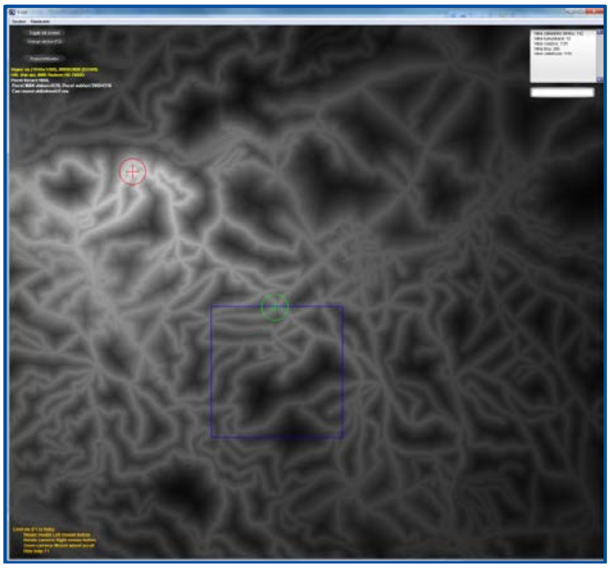

Fig.3- Path Optimality Map: Initial Path Point in Red Circle & Optimal Destination Point in Green Circle within selected Destination Area (Blue Square)

Therefore, despite all these elements that represent challenges, it is evident that in these context the introduction of autonomous unmanned systems to substitute people provide a great opportunity to reduce risk to human life.

5 MODELING USE & AI ALGORITHMS

The proposed application field requires the models and simulators to be used for different purposes; for sure crucial objective is to support requirement and configuration definition during early design in order to identify the most promising platform type (e.g. UGV or UAV, wheeled or tracked, single domain vs. multi domain) and operational mode (e.g. single platform, multi platform, collaborative, etc.).

Fig.4- UAV moving inside the Industrial Plant

Fig.5- UAV supervising UGV relief mission

In this phase the simulation should act on relaxed fidelity constraints, therefore the evaluation of confidence band should be carried out and controlled to verify and validate the model, check the result consistency and support comparative analysis among different configurations (Richards. et al.2002; Massei et al.2003). In addition it should be outlined that M&S plays decisive role within AI (Artificial Intelligence) algorithms and decision support approaches at all levels; for instance, the *deployment destination optimization*, including *obstacle avoidance* and *multi-criteria compromise*, could be calculated, for every possible path option and destination within operations area, in real time (approx. 50ms, 2x2 Km, area attribute resolution 1x1m) thanks to the multi-path algorithm improvements, as presented on figure 3 (Mazal 2012). Based on the initial path point and criteria, *Path Optimality Map* could significantly differ and "opens the door" for additional analyses, like trivial destination optimization demonstrated on figure 2 & 3. Path optimality map calculation is based on minimization of purpose function:

$$POM_{x,y} = \min \rightarrow \sum_{i=1}^{M} K_{I_i,J_i} \qquad (1)$$

where:

$K_{x,y}$ 2D weighted "safety" matrix of operational area, derived from the criteria's and analyses

I_i, J_i Mathematical progressions set coding the individual components/axes of the path.

$POM_{x,y}$ Path optimality matrix

Also must be fulfilled the condition:

$$\forall\, i\ \in (1..M) => (|I_{i+1} - I_i| + |J_{i+1} - J_i|) <= 2 \quad (2)$$

In facts, the M&S should be reach quite high fidelity levels in order to address engineering and finalize the check up of the whole new solution as virtual prototype. In this case, the technical and operational tests could be executed within a virtual, but realistic, environment, to verify the performance and to measure the reliability, effectiveness and efficiency of new solution based on autonomous systems; in case of configurations dealing with multi-platform collaborative UxVs, the use of simulation turn to be even more crucial as well as when it is required collaboration with traditional assets and other plant systems.

A not secondary aspect is the training of personnel in charge of managing the autonomous systems. This aspect deals with both traditional man-in-the-loop training (e.g. the pilot of a small UAV) as well as with the man-on-the-loop education and training dealing with people in charge of supervising the use of multiple autonomous systems assigning high level tasks (Magrassi 2013). This secondary kind of skills will become more and more important in the future and simulation will be fundamental to prepare these new supervisors. Last, but not least, M&S could be used to support preventive definition standing operational procedures and operational planning to be ready to act in case of necessity to carry out critical operations in challenging cases. For instance for optimizing and evaluating all risks of a mission for inspecting a confined space very hard to access, or to deal with plant area affected by an accident such as a fire. Considering these different objectives for simulation in this context, it could be necessary to consider the use of different models, so hereafter it is proposed a paradigm and an architecture that could simplify development, enhance maintainability and reusability with limited costs and efforts.

6 MODELING PARADIGM & ARCHITECTURE

As anticipated the use of Autonomous Systems in industrial plant is a challenge from many different aspects, pretty innovative in terms of implementations, and requires to be flexible for different uses; due to these reasons, it is proposed to develop a flexible approach that could maximize usability with limited efforts; the authors propose hereafter the MS2G (Modeling, interoperable Simulation and Serious Games) paradigm that combines interoperability, high fidelity simulation and serious games (Bruzzone et al.2016c); indeed this approach allows to develop intuitive virtual and augmented representations running on multiplatform, from CAVE (Cave Automatic Virtual Environment) down to smartphones; in this way it becomes possible to develop models that benefits from interoperability standard HLA (High Level Architecture) from technological point of view and that have usability and interactivity of games.

Fig.6- UGV carries an injured out of contaminated area

The international standard (IEEE1516) allows to federate different simulators and also real equipment into an open architecture; so by this approach it becomes possible to complete tests on the federation of simulators integrated also with external systems and sensors (Bruzzone et al.2016c).

In order to guarantee different uses and different fidelity models, the proposed approach adopts the architecture presented in figure 1, where meta-models could be used as substitute of federates during early development phases or in case of criticalities in data & knowledge availability as it happen in Lean Simulation (Massei et al. 2003). Among the elements of this federation of models and simulators it is obviously very important to include the IA and AI systems (Intelligent Agents and Artificial Intelligence) able to guarantee the autonomous capabilities of the UxV (Stodola et. al. 2014; Massei; Bruzzone et al.2016a). In facts this approach guarantee the possibility to overpass several of the challenges of conceptual interoperability and to get benefits of simulation technology advances (Bruzzone et al.2016c).

7 CASE STUDY: CRISIS & MULTIPLE COORDINATED TASKS

In order to validate the concept, it is hereafter proposed the case of an innovative system for addressing crisis and operations industrial plants developed by the authors; the scenario used deals with an accident including explosions, fires and hazardous material spills affecting an industrial complex; the air contamination and fire provide a challenge to use unmanned vehicles to define the dangerous area outside and conduct inspections outdoor and inside the building; the authors propose a combined use of UAV and UGV taking care of collecting measures and samples, detecting people inside and completing triage assessment (Grocholsky et al.2006; Tanner 2007a; Bruzzone 2016c).

UAVs are in charge of the majority of measurements to finalize the scenario picture and its dynamics while the UGVs provide a direct support for collecting the injured people and carry them out to the safe areas where first responders such as firefighters and ambulances are available as proposed in figures 2, 3 and 4 (Bruzzone et al.2016b). In facts the UGV could collect injured people and transport them out of contaminated areas (see figure 5 and 6); it is very interesting from this point of view to include into the federation also a simulator of the patient including dynamic reaction to events (e.g. his handling) and to environmental conditions (e.g. crossing areas affected by other contaminant agents) to create an even more comprehensive scenario (Bruzzone et al.2012). The operations require the UxV to be able to move within the whole industrial complex: inside as well as around, for instance in order to be able to identify the safe perimeter in terms of contamination and to continuously monitor the situation. In addition, it is necessary to conduct inspections in outdoor areas and inside the buildings considering the complex obstacles and electromagnetic interferences, the degraded sensor performance as well as the consumption of the UAV and UGV battery based on the subsystem and functions activated on board. These challenges suggest to develop a collaboration capability within an heterogeneous network of autonomous systems (Maravall et al.2013; Bruzzone et al. 2013b). It is fundamental to introduce Performance Indexes to evaluate the effectiveness and efficiency of different configuration as it has been done, for instance, in reference to bordering the contaminated area in the industrial plant:

$$Ace(t) = \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{\mathrm{FIA}_{i,j}(t)}{\mathrm{H}(\mathrm{L_{i,j}(t)} - \mathrm{Ll})} \quad (3)$$

$$Acrp(t) = t^*/Acr(t^*) \geq Acr(t_g) \forall t_g \in [t_0, t] \quad (4)$$

$$Acr(t) = t^*/Acr(t^*) \geq tl \text{ and } t^* \leq t \quad (5)$$

Ace(t) Detected Contaminated Area percentage
n number of strips used for classify horizontally the 2D map of the area around the contaminated plant
n number of strips used for classify vertically the 2D map of the area around the contaminated plant
t current simulated time
t_0 simulation starting time
H(x) Heavyside function of x
i i-th strip considered horizontally
j j-th strip considered vertically
$\mathrm{FIA}_{i,j}(t)$ Function [0,1] returning if the area is identified As contaminated by UxV systems at t time
$\mathrm{L}_{i,j}(t)$ Real Contamination Level in the i-th and j-th area at t time
Ll Safety Concentration Limit for contaminant Agent
Acrp(t) Responsiveness at t time respect best achieved identification of contaminated areas
Acr(t) Responsiveness at t time respect best full correct identification of contaminated areas

Obviously in this case, the simulation is the best technique to conduct the tests and experiments; this consideration is valid for the virtual prototyping of a single platform (including sensors and controls) and even more important for a combined system based on multiplatform and multi-domain collaboration as that one proposed here. As anticipated, the paradigm adopted is MS2G (Modeling, interoperable Simulation and Serious Game) and the tests have been carried out

by using the SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering), a virtual immersive interactive interoperable CAVE developed by Simulation Team, providing virtual and augmented reality features to users (Bruzzone et al.2016c).
The SPIDER allows to carry out multiple experiments easily and to complete the VV&A by experimental design (Montgomery 2000).
In addition to dynamic quantitative techniques it is also possible to get face validation by Subject Matter Experts (SME) by supervising the multi domain autonomous system collaboration as well as to the dynamics of the disaster evolution affected by stochastic factors.
It is interesting to note that the quantitative results of the simulation (e.g. contamination levels, battery level, etc.) could be presented as augmented reality information during the evolution of the simulation.
In facts, this simulator is integrated with AI (Artificial Intelligence) provided by Simulation Team and by Czech University of Defence for addressing different issues (Mazal et al.2012; Massei et al.2014).
For instance, the IA-CGFs from Genoa University allow to take care of coordination among UxVs and other traditional assets (Bruzzone et al.2011). Vice versa the IA from Czech University are focusing on routing and obstacle avoidance as well as on planning issues (Stodola et al.2014a; Stodola & Mazal.2010a).
The proposed scenario is pretty challenging and the demonstration carried out in this context allows to define algorithms and configurations that result reliable for operating in this kind of environment.
For instance, as anticipated, the simulator estimates battery consumptions related to the different operational modes and sensor activations while the positions of fires and areas subjected to risk of explosions are evaluated for identify most convenient path during rescue missions with and without injured people on board for the UGV or, for the UAV, during different task accomplishments.
Some synthetic experimental results are summarized hereafter about the test conducted indoor and outdoor by collaborative use of the autonomous systems respect regular operations and emergencies.

8 CONCLUSIONS

In the proposed case, it is outlined the importance to apply conceptual interoperability in development of innovative autonomous system solutions; in facts by combining the M2SG approach with AI, such as the intelligent navigation developments, it becomes possible to multiple the effectiveness of the solutions based on the autonomous systems. The different modeling approaches devoted to support the development of these new solution, should be based on innovative interoperable architecture in order to finalize the match among different models covering specific issues. In this way the whole federation of simulators and models, combining all different aspects together, is able to reproduce the challenges of the whole mission environment.
The proposed example confirms the capability offered by modern simulation paradigms and AI algorithms in supporting the introduction of autonomous systems within new challenging scenarios.
Currently the authors are working towards the development of additional projects devoted to carry out specific tasks, actually assigned to humans, to improve safety and security in dangerous environments in industrial plants and defense scenarios.

REFERENCES

Ackerman E. Guizzo E. (2015) "DARPA Robotics Challenge: Amazing Moments, Lessons Learned, and What's Next", IEEE Spectrum, June 11

Apvrille, L., Roudier, Y., & Tanzi, T. J. (2015) "Autonomous drones for disasters management: Safety and Security Verifications", Proc. 1st IEEE URSI Atlantic, May

Bachmann, S.D.O.V., & Gunneriusson, H. (2014) “Terrorism & Cyber Attacks as Hybrid Threats”, Journal on Terrorism & Security Analysis

Brown G.,Carlyle M.,Salmerón J.,Wood K.(2006) "Defending Critical Infrastructure", Interfaces, 36(6), pp.530-544

Bruzzone A.G., Longo F., Agresta M., Di Matteo R., Maglione G.L., 2016. Autonomous systems for operations in critical environments. Simulation Series, pp. 17.

Bruzzone A.G., Longo F., Massei M., Nicoletti L., Agresta M., Di Matteo R., Maglione G.L., Murino G., Padovano A., (2016). Disasters and emergency management in chemical and industrial plants: Drones simulation for education and training. Lecture Notes in Computer Science, Volume 9991 LNCS, 2016, pp. 301-308.

Bruzzone A.G., Massei M., Di Matteo R., Agresta M., Franzinetti G., Porro P. (2016e) “Modeling, Interoperable Simulation & Serious Games as an Innovative Approach for Disaster Relief”, Proc.of I3M, Larnaca, Sept. 26-28

Bruzzone A.G., Frascio M., Longo F., Massei M., Siri A., Tremori A. (2012). MARIA: An agent driven simulation for a web based serious game devoted to renew education processes in health care. 1st International Workshop on Innovative Simulation for Health Care, IWISH 2012, Held at the International Multidisciplinary Modeling and Simulation Multiconference, I3M 2012, pp. 188.

Bruzzone A.G. Tremori A., Massei M. (2011) "Adding Smart to the Mix", Modeling Simulation & Training: The International Defense Training Journal, 3, 25-27, 2011

Fabiano, B., Pistritto, F., Reverberi, A., Palazzi, E. (2015) “Ethylene-air mixtures under flowing conditions: A model-based approach to explosion conditions”, Clean Technologies and Environmental Policy, 17 (5), 1261-1270

Feddema, J.T.; Lewis, C.; Schoenwald, D.A., (2002) "Decentralized control of cooperative robotic vehicles: theory and application, "Robotics and Automation, IEEE Transactions on, vol.18, no.5, October, pp.852,864

Ferrandez J.M., De Lope H., De la Paz, F. (2013) “Social and Collaborative Robotics”, International Journal Robotics and Autonomous Systems, 61, 659-660

Grimaccia, F., Aghaei, M., Mussetta, M., Leva, S., & Quater, P. B. (2015) “Planning for PV plant performance monitoring by means of unmanned aerial systems (UAS)” International Journal of Energy and Environmental Engineering, 6(1), 47-54

Grocholsky, B.; Keller, J.; Kumar, V.; Pappas, G., (2006) "Cooperative air and ground surveillance", Robotics & Automation Magazine, IEEE, vol.13, no.3, Sept., pp.16-25

Guizzo E., Ackerman E.(2015)"The hard lessons of DARPA's robotics challenge", IEEE Spectrum, 52 (8), pp.11-13

Lim, J. Shim I., Sim O., Joe H., Kim I., Lee J., Oh J.H. (2015) "Robotic software system for the disaster circumstances: System of team KAIST in the DARPA Robotics challenge finals", Proc. of 15th IEEE-RAS Int. Conf. on Humanoid Robots, Humanoids, Nov., pp. 1161-1166

Magrassi C. (2013) "Education and Training: Delivering Cost Effective Readiness for Tomorrow's Operations", Keynote Speech at ITEC2013, Rome, May 22-24

Maravall D., J. de Lopea,b, R. Domíngueza, (2013) "Coordination of communication in robot teams by reinforcement learning", Robotics and Autonomous Systems 61, pp.661–666

Massei, M. & Solis, A. (2016) "Chairs' Message", 15th International Conference on Modeling and Applied Simulation, Larnaca, Cyprus, September

Massei M., & Tremori A. (2014) "Simulation of an Urban Environment by Using Intelligent Agents within Asymmetric Scenarios for Assessing Alternative Command and Control Network-Centric Maturity Models", the Journal of Defense Modeling and Simulation, 11(2), 137-153

Massei, M., & Simeoni, S. (2003) "Application of Simulation to Small Enterprise Management & Logistics", Summer Computer Simulation Conference, Society for Computer Simulation International, pp. 829-834

Mazal, J., Stodola, P., & Mokrá, I. (2012) "Tactical and Autonomous UGV Navigation", Mechatronics, 439-443

McCurry Justin (2017) "Dying robots and failing hope: Fukushima clean-up falters six years after Tsunami", The Guardian, March 9

McLeod, J. (1968) "Simulation: the Dynamic Modeling of Ideas And Systems with Computers", McGraw-Hill, NYC

Merabti, M., Kennedy, M., & Hurst, W. (2011) "Critical infrastructure protection: A 21 st century challenge", Proc. of IEEE Int.Conf. on Communications and Information Technology, ICCIT, March, pp. 1-6

Moranduzzo, T., & Melgani, F. (2014) "Monitoring structural damages in big industrial plants with UAV images", Proc. of IEEE International Geoscience and Remote Sensing Symposium (IGARSS), July, pp. 4950-4953

Montgomery Douglas C. (2000) "Design and Analysis of Experiments", John Wiley & Sons

Nikolic, J., Burri, M., Rehder, J., Leutenegger, S., Huerzeler, C., & Siegwart, R. (2013) "A UAV system for inspection of industrial facilities", Proc. of IEEE Aerospace Conference, March, pp. 1-8

Palazzi, E., Caviglione, C., Reverberi, A.P., Fabiano, B. (2017) "A short-cut analytical model of hydrocarbon pool fire of different geometries, with enhanced view factor evaluation", Process Safety and Environmental Protection, August

Pugh, M. (2005) "The political economy of peacebuilding: a critical theory perspective" International Journal of Peace Studies, pp.23-42

Rani, C., Modares, H., Sriram, R., Mikulski, D., & Lewis, F. L. (2016) "Security of unmanned aerial vehicle systems against cyber-physical attacks", the Journal of Defense Modeling and Simulation, 13(3), pp.331-342

Reverberi, A.P., Klemeš, J.J., Varbanov, P.S., Fabiano, B. (2016) "A review on hydrogen production from hydrogen sulphide by chemical and photochemical methods", Journal of Cleaner Production, 136, 72-80

Richards A., J. Bellingham, M. Tillerson, and J. P. (2002) "How: Co-ordination and control of multiple UAVs", Proc. of the AIAA Guidance, Navigation, and Control Conference, Monterey, CA, Aug., AIAA-2002-4588

Ross, S., D. Jacques, M. Pachter, J. Raquet, (2006) "A Close Formation Flight Test for Automated Air Refueling", Prof. of ION GNSS-2006, Fort Worth, TX, September

Shukla, A., & Karki, H. (2016) "Application of robotics in onshore oil and gas industry", Robotics and Autonomous Systems, 75, pp.490-507

Stodola, P., Mazal, J., Podhorec, M., & Litvaj, O. (2014) "Using the ant colony optimization algorithm for the capacitated vehicle routing problem" Proceedings of 16th IEEE International Conference on Mechatronics-Mechatronika, December, pp. 503-510

Stodola, P., & Mazal, J. (2010a) "Optimal location and motion of autonomous unmanned ground vehicles", WSEAS Transactions on Signal Processing, 6(2), 68-77

Stodola, P., & Mazal, J. (2010b) "Autonomous motion of unmanned ground vehicles in general environment", Proceeding of the International Conference on Recent Advances in Signal Processing, Robotics and Automation, February, pp. 226-231

Sugisaka, M. (2011) "Working robots for nuclear power plant disasters", Proc. of 5th IEEE International Digital Ecosystems and Technologies Conference, DEST, May, pp. 358-361

Tanner H. G. (2007a) "Switched UAV-UGV cooperation scheme for target detection", IEEE International Conference on Robotics and Automation, Roma, Italy, April, pp. 3457-3462

Tanner H.G., D.K. Christodoulakis, (2007b) "Decentralized cooperative control of heterogeneous vehicle groups", Robotics and Autonomous Systems 55,pp 811–823

Tether, T. (2009) "Darpa Strategic Plan", Technical Report DARPA, May

Tilbury, D., & Ulsoy, A. G. (2011) "A new breed of robots", Mechanical Engineering, 133(2), 28

Vail D. and M. Veloso, (2003) "Dynamic Multi-Robot Coordination", Multi-Robot Systems: From Swarms to Intelligent Automata, Vol II, pp. 87-100

Wooldridge, M.; Jennings, N. R. (1995) "Intelligent Agents: Theory and Practice", Knowledge Engineering Review, 10 (2), 115–152

SIMULATION AS DECISION SUPPORT SYSTEM FOR DISASTER PREVENTION

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ABSTRACT
This paper describes the overall architecture of a simulator developed by Simulation Team and Genova University to address the problem of strategic decision making related to prevention and mitigation of natural disasters risks. The proposed approach combines a Decision Support System for supporting decision makers in strategic planning with interoperable simulation and serious games. The scenario used for the validation in this case focuses with a particular attention on hydrogeology and related risks within urban environments. The authors propose a multilevel and multi resolution simulation able to match the models of the flooding with that one of the population reproducing interest groups as well as single people. Indeed the population is simulated by intelligent agents (IAs) that include physiological, social and psychological parameters reproducing feelings and emotions that allow them to live and move inside the virtual city both in normal conditions as well as during the disasters.
In facts in normal conditions works devoted to serve as preventive actions devoted to prevent certain events and or mitigate their impact are carried out; vice versa during the crisis, decisions change addressing the identification of convenient operational planning and/or evacuation site. Each time, an action is undertaken by the decision makers, the IAs react dynamically by changing their feelings and their political consensus, so it becomes possible to plan the actions in an effective way by maintaining the consensus and support of the population.

Keywords: Flood Simulation, E-Government, Intelligent Agents, Decision Support Systems, Political Consensus, Social Networks

1 INTRODUCTION

Urban decision makers constantly need to face many challenges during their governance. Indeed they have often limited resources both in terms of time and money. Their governance last generally around 3-5 years and this is a short time compared to the completion time of certain big projects such as civil works such as floodways, dikes and other large infrastructures. The challenge for the local decision makers does not deal only with time constraints, in facts the central administration often reduce the annual budget of local municipalities that consequently have to limit their investments or have to rise local taxes to respect the annual budget.

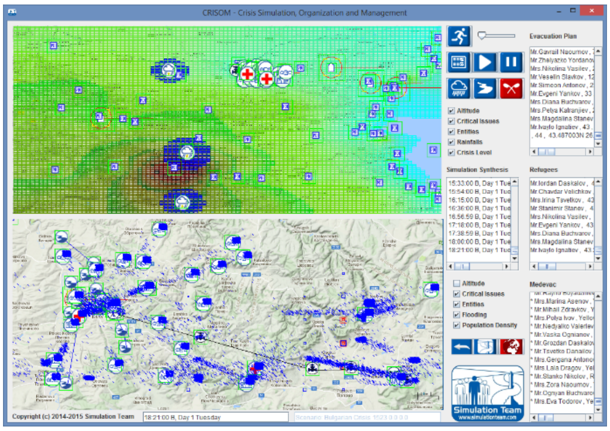

Figure 1: ST_CRISOM main interface

Today the impact of natural disasters is reinforced by several phenomena; for instance climate change increase frequency and intensity of these events as well as urbanization; in facts today more than 50% of world population is living in urban areas. These aspects increase the impact of flooding, hurricanes exponentially due to the high concentration of humans for square kilometer. One of the most recent and devastating confirmation of this problem is hurricane Harvey (Bromwich 2017).
For instance, urbanization amplifies the effect of flooding not only due to the increase of population density, but also as consequence of urban concreting; in facts this aspect requires a big attention from urban decision makers in planning the new constructions in order to respect local hydrogeology and avoid floods to be magnified by overbuilding (Jia et al. 2008; Lankao & Qin 2011). In the last decade several countries has experienced a number of unusually long-lasting rainfall events that produced severe floods and other extreme events such as big landslides (Schirmer et al. 2013; Howard & Israfilov 2012; Leichenko 2011). The importance of projects, addressing protection from risks related to hydrogeology, is often underestimate and many activities are postponed or reduced since they are extremely costly and the popularity is often “hidden” compared to other more popular and less costly investments. In addition politically opposing parties and different interest groups could act against the Decision Makers introducing delays and obstacles that compromise these project. In facts, the decision makers are political entities, and they need to keep constantly “an eye open” to citizen consensus during their mandate: each decision produces effects on the population.

Figure 2:ST_CRISOM User Interface

Therefore popular & unpopular decisions influence statistically the average consensus and in some case, extreme situations, could lead also to the risk of delegitimization of current governance bringing unexpected early elections. (Rimlinger 1971).

The “art” of good governance is based on the capability of decision makers to address major issues based on priorities and in respect of available resources (e.g.money, time and people) by activating and completing projects and investments in different areas such as Environment, Economy, Welfare, Security, etc. (Bruzzone et al. 2014a). The set of all the possible investments and decisions is huge and there are several categories of potential investments, for example:

- Urgent/Non Urgent
- Long Realization Time/Short Realization Time
- Popular/Unpopular
- Cheap/Costly
- Useful/Not Useful
- Urgent/non Urgent

Each of this choice have a different specific impacts over multiple domains finance, environment, consensus, safety, etc. For example cleaning the river has a prompt results in population consensus and a medium economical cost; on the other side, a civil work such as rising the level of a bank in a particular point, or building a new floodway have an higher cost, and a longer time reaction time from population since it require more time; by the way sometime the works required to complete the project could be perceived in negative sense by the population for several issues (e.g. noise, impact on traffic, etc).

It is evident that most of this factors are affected by uncertainty and influenced by stochastic factors (e.g. weather working days, people perception, etc.).

These considerations underline the potential of simulation for supporting the decisions and for testing and evaluating the different hypotheses and even to underline emergent behaviors and situations (Ören and Longo, 2008) in different types of real world systems; in facts also the use of serious game could be pretty useful to provide a framework to share, through the web, multiple different proposals with the population. Indeed modern crowdsourcing concept based on this approach is very interesting beacuse it allows to collect active proposals and suggestions by people as well as for improving communications with citizens and building consensus (Rossetti et al.2013).

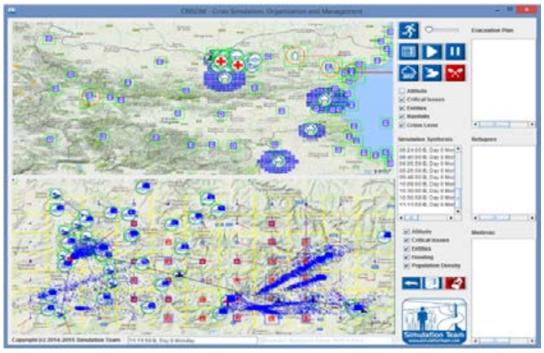

Figure 3: rain propagation in ST_CRISOM

2. E-GOVERNMENT, OPEN DATA AND THE IMPORTANCE OF COMMUNICATIONS

Nowadays Twitter, other Social Networks and Blogs are “massive” communication channels, often considered more effective compared to traditional ones (Baruah 2012; Trusov et al. 2009; Garton et al. 1997)

These resources represent an extremely powerful tool, indeed communication strategies have a great potential to support the establishment of good and effective governance (Heeks, 2001). In facts this consideration could be used by Public Administrators (PA) in order to create an effective E-Government system:

- From PA to Citizens: to publish information, results, alerts
- From Citizens to PA: to collect feedback and to “keep an eye” on the city by monitoring the situation based on citizen posts as well as on their web activity

In this way the citizen participation to local politics could be improved and their consensus could be monitored through social networks and web activities. Such kind of information is available to be fused with open data, statistics and census information becoming extremely powerful; indeed urban municipality have access to big data characterized by a big potential, that often are not used for supporting decision makers for several reasons such as:

- Availability of Data and Models: very often Public Administrations have some model or simulation tools as well as dataset, but usually the models are almost disconnected; for instance, frequently, the data require additional preprocessing to be transformed in the required formats and not trivial manual elaboration and/or filtering are necessary.
- Obsolescence: frequently the data are not updated constantly and their validity is expired. In similar way the models could turn obsolete or loose their fine tuning if not used frequently.
- Entry Barriers: databases and models are often used by analysts, in many cases they are not intuitive and require the advanced scientific and/or technical skills to be used. In addition, the models are not designed, usually to be used directly by decision makers, so it is missed such feedback to refine them.

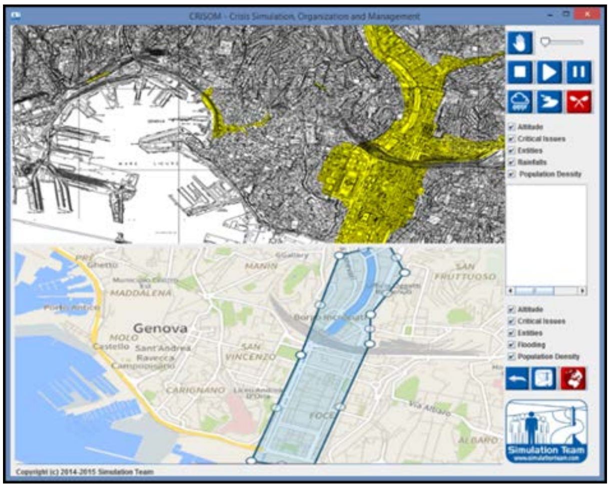

Figure 4: CRISOM Map Editing Tool

- Organization Complexity: Public Authorities have a complex bureaucratic structure often with partial and not interconnected substructures such as local police, Civil Protection, Statistical Office, Mobility office etc all these entities often use their own local dataset missing the chance to share common information and models.
- Privacy: PA owns several information about its citizens, buildings, infrastructure etc. but often don't share such data due to privacy reasons (i.e. health and other sensitive information). Often the privacy concerns limit the data sharing much more respect the effective regulations due to the pusillanimous of some officers, vice versa such information would be extremely useful also in the form of aggregate data set. (Floridi, 2014).

Thanks to the Open Data, several PA are now publishing much more information about their municipalities and these are becoming more and more accessible. Accessibility often corresponds to reliability considering that the review by third party user of the database contents allows to identify errors and inconsistencies and to apply corrective actions (Kassen 2013).
These Open Data are available often to everyone, so they represent new opportunities for the e-government and for developing new tools for Decision Support Systems, Crowdsourcing and Serious games for improving communications with citizens and for collecting their feedbacks (Janssen et. al, 2012; Kitchin, 2014).
From this point of view the authors decided to develop a simulation approach devoted to benefits from the huge quantity of available open data from the web and ready to reproduce population by effective human behavior models.

3. ST_CRISOM

Simulation–Team Crisis Simulation Organization Management (ST_CRISOM) is a simulation framework, developed by Simulation Team and DIME University of Genova, with special attention to reproducing disasters and decision makers planning. Indeed ST_CRISOM is part of a "suite" of different simulators dedicated to Disaster Emergency Simulation that are adopting HLA (High Level Architecture) interoperability standard.
In facts, ST_CRISOM enables the possibility to generate and simulate disasters and to estimate the effectiveness of different actions carried out to prevent, mitigate and eventually manage the crisis. In facts this simulator reproduce both urban areas as well as country side and it could be federated with other tools by means of a Run Time Infrastructure (RTI).
ST_CRISOM is able to run real time and faster-than real time, so it could be used to check validity and robustness of different alternatives; in facts this allows to apply data farming and risk analysis for decision support over complex scenarios (Barry et al.2004). In addition ST_CRISOM has passed integration test within CRISOM HLA Federations, so it is available to interoperate with other simulators developed by DIME-Simulation Team; (i.e. IDRASS, DIEM-SSP, IA-CGF NCF NCF EQ, TRAMAS Katrina Like, DIES IRAE, SIMCJOH VIS & VIC, MARIA) that could further enhance its capabilities in complex scenarios (Bruzzone et al. 2011, 2015a; Massei et al. 2014).
ST_CRISOM is equipped by an intuitive interface for users that support a Multilevel and Scalable approach (tactical/operational/strategic level); originally this solution was including different simulation models for addressing multiple different crises:

- Explosions
- Hazardous Material Fallout
- Flooding

These simulation models are used to identify areas and to define items, objects, buildings, plants, infrastructure and people affected by such event.
ST_CRISOM have a multi-layer resolution that could be tuned by the users. Such capability allows to consider different layers and to overlap available information provided by different sources and to share them within the simulation through Geo-Referenced data.
In facts, ST_CRISOM consider different layers:

- Natural: Orography of the terrain as well as information on sea, woods, rivers, aquifers and Hydrographic basins
- Urbanized: households, buildings, industries, transport networks, point of attraction
- Infrastructures: pipelines, power grid, and point of interest (hospitals, schools, stadium etc.)
- Population: distribution in villages and quarters, individual life cycle, individual preferences, families and social networks
- Communications & Social Networks

ST_CRISOM allows to simulate humans from single entity (i.e. individual) up to aggregated level of the entire population of a city according to the users' needs and the data available. Hereafter some major different parts of the ST_CRISOM are described.

3.1 Model of the Orography

Simulation Team have developed an acquisition algorithm for importing the Digital Elevation Map of a given area from the web into ST_CRISOM databases. In particular ST_CRISOM is already able to import the Orography of a certain area by converting a shape file into a discrete surface composed by polygons. Such area have a variable resolution according to the level of details required by the simulation and according to the overall efficiency that is related to the extension of the area to be investigated.

3.2 Rain Generation Model

ST_CRISOM is equipped by a rain simulation model that allow to simulate the evolution of a perturbation. The model is stochastic in order to be more realistic and simulate the "uncertainty" affecting the decision makers. Rain probability and intensity (e.g. mm/hour) as well as cloud propagation are simulated considering the meteo-forecasts and potential deviations; indeed the available measures of wind speed & direction, humidity, temperature and other stochastic variables, concur to create a realistic propagation of the perturbations; therefore ST_CRISOM includes special algorithms devoted to spread these data in space, over the whole area, and in time, respect the whole temporal horizon, by applying the different conservation laws.

3.3 Rain Absorption Model

This model is needed for simulating the rain absorption from the terrain; indeed the water absorption factor of rain strongly depends on many parameters such as type, state (e.g. frozen ground), roughness and inclination and orientation of the terrain; that is the reason why setting the right coefficient it requires proper tuning techniques. In addition it is necessary to distinguish:

a) Urban areas where there is presence of drainage networks composed by roofs, roads and other man made items
b) Not-asphalted areas, where there are also different terrain typologies with different absorption behavior (i.e. rocks, clays, grit) and different conditions. Indeed if the terrain is already wet from the previous days the model should consider that its absorption will be lower.

3.4 Hydraulic Models

Hydraulic models reproduce in details the rivers and the hydrological basins. These models allow to simulate the water streams in the different section of the rivers and the local flooding phenomena due to the overcoming of the maximum water level. Such data can also be shared with other simulators through HLA and/or elaborated by ST_CIPROS VIC (Simulation Team Civil Protection Simulator - Virtual Interoperable Simulation) for reproducing the 3D flooding local model (Fig. 2). Indeed ST_CRISOM is HLA compliant and it can be federated by means of the RTI to other software in real time (Bruzzone et al. 1998, 2015b).

3.5 Urban Mobility Models

These model represents the population movements in the city and between towns, plants and infrastructures located in the region of interest. The City is divided into zones and the people objects at their creation have assigned homes and working places based on their specifics characteristics; these correspond to zones that during simulation become attraction and generation points. The people objects by moving around allow to compute the distribution of the population and its activities based on their specific life cycle and their reactions to events. In this way the crowd change over the different zone of the city and according to several boundary conditions and events, including floods, such as hour of the day, meteorological conditions, day type (working day/holiday), other special events like fairs or football matches etc.

3.6 Entities & Points of interest

ST_CRISOM simulates several different Entities (e.g. ambulances, mobile command post) and Points of Interest (PoIs) such as schools, hospitals, industrial facilities, plants, pipelines and other "hot point" that are important in case of an emergency such as a flood.

3.7 Damage Models

Damage models match the flooding dynamics resulting from the simulation to the other layers, particularly with the population and Entities and PoIs; indeed ST_CRISOM calculates dynamically the list of the entities that are affected by the flooding over the different areas, providing their details (i.e. name, sex, age, health status etc). Such information are organized to support evacuation plans as well as support operation and could be visualized dynamically in disaggregate or aggregated according to the desired resolution for the virtual environment.

4. IA & POPULATION SIMULATION

ST_CRISOM is designed for being available through the web and to reproduce the town reactions to decisions as well as to crises; in this context it is fundamental to reproduce the population, so the Intelligent Agents (IAs) are used by ST_CRISOM to simulate the human behaviors considering complex aspects such as rational decision making, emotional and irrational behavior resulting from individual perception as well as social interactions. Indeed ST_CIPROS VIC reproduce individuals on different layers:

- People Objects (POs) representing entities devoted to cover the single individual as well as a small group or a family
- Interest Groups (IGs) representing groups of people with common characteristics and interests

People Objects are integrated into a social network connecting different entities due to family or friendship liaisons, while Interest Groups are interconnected by mutual relationship relationships; obviously each PO is connected also to multiple IGs representing the groups

to what he belongs and, vice versa, IGs is linked to many POs representing its members.
These multi layer multi link social networks represent the population and all corresponding social interactions.
In facts, the familiar relations and social networks are simulated by IA-CGF (Intelligent Agent Computer Generated Forces) and have been developed by the Simulation Team during the years and applied in different context (Bruzzone et al. 2011).
ST_CRISOM simulates each single individual as an intelligent entity with several functions representing their emotions (e.g. fear, stress, aggressiveness, political consensus) that evolve during the simulation based on its perception of events. Indeed The ST_CRISOM is a stochastic, discrete event based simulation that adopt MS2G paradigm (Bruzzone et al.2014a).

4.1 Single Entity Layer

This is the basic layer where it is possible to recreate population based on open data. Here, the POs are created based on statistical distribution created by the available open data that feed the Configuration Objects defining the different element of the population (e.g. a Neighborhood of a city, the workers of a business sector, the followers of a leader). The following parameter are considered:

- Age
- Gender
- Living Zone
- Nationality
- Religion
- Marital Status
- Political Party
- Level of Instruction
- Individual Income
- District of residence
- District of work
- District for leisure activities

4.2 Family Aggregation Criteria

This elements represent the aggregation criteria for single individuals to become a family and are structured in terms of parameters considered for verifying the compatibility of a stochastic generated family: number of component, importance of social differences, average incomes, number and age of the children, etc.

4.3 Social Aggregation Criteria

This layer allow to connect each individual to other entities by reproducing their social relationships including among others: Friendship, Workplace connections and specific Social Networks. Such components are simulated by means of compatibility algorithms similar to that ones of the families and currently the authors are working on creating special models for Web Social Network Simulation to be used during training sessions and for educating the decision makers to take into account the feedbacks from these new media channels.

5. ST_CRISOM FUNCTIONALITIES

ST_CRISOM is designed in order to be accessible as web applications to be available on the cloud and it supports the following functionalities:

a) User registration: the registration page allows to keep record of the user data and supports different account type are configured:

a. PA Decision Maker
b. PA Analyst
c. Citizen

Such differentiation is important to preserve privacy of some data and other information that PA cannot or does not desire to share and publish. Such characteristics activate and deactivate some functionalities, for example only a Analyst is enable to change parameters of flooding model.

b) Loading the Common Interface - Geo-Map Tool
This tool is based on an open source map with several layers (topographic, political, etc.). Several Points of Interest (PoIs) are displayed, geo-referenced over the map, classified as macro-categories. ST_CRISOM includes the following basic classes, even if other classes could be added easily:

- School (e.g. Primary, Secondary, Comprehensive Institute, Universities, etc.)
- Hospital
- Museum
- Commercial Center
- Other big PoIs (i.e. aquarium, stadium, fair etc..)

c) Map Editing: ST_CRISOM map includes an editing tool that is devoted to add additional layers from existing maps (i.e. hydrological basin, flood risk map). PoIs could be also added easily by defining their type, coordinates and attributes.

d) Sensors and Cameras: this functionality is available only for PA users and it allows to visualize the following elements:

- The available camera in the city
- The available sensors in the city (i.e. rain gauges)

e) Prediction tools: these functionalities allow to create the future population in reference to a reference year in order to investigate its structure and related social networks. Indeed ST_CRISOM support data sets covering future population up to 2030.

f) Population Generation: ST_CRISOM reproduce population considering individuals, families, social network and interactions over the whole town. The generation process adopt Monte Carlo techniques based on Configuration Groups created through the data fusion of open data. The overall process is following

- ➢ Open Data Access: open data available from public sources are used to update ST_CRISOM databases
- ➢ Population Data Fusion: the open data could have different granularities, for instance it can be referred to different types of urban subdivisions; so it could be necessary to combine them in order to create a comprehensive and consistent set of

Configuration Groups able to define the whole population; for this purpose it should be necessary to design and implement tailored data fusion algorithms.

- Individual Generation: the single individuals are generated as people objects from the Configuration Groups applying Monte Carlo Technique, aggregation criteria and the compatibility algorithms on the zones. In this way the POs are located on the terrain, for instance, in terms of home and work place; in order to speed up the simulation, it is possible to aggregate the individual into similar entities such as family
- Interest Group (IG) Creation and Population: from the generated individuals are extracted the main groups and created the mutual links between IGs and POs.
- Social Network Generation: the social networks are created by applying compatibility algorithms and aggregation criteria among themselves; in this way families are create in consistency with general data of the area.
- Interest Group Network: the IGs are interconnected in the form of a dynamic graph considering mutual attitudes and connections based on general characterization of the area that could be fine tuned by analysts.

g) Urban Mobility Layer: the urban mobility layer allow to simulate the people movement inside the city. For the ST_CRISOM purposes, people move from their home zone to working zone of the city and back during working periods as well to relax areas in free time. Urban mobility layer is used to evaluate the dynamics of people object on the map. During crisis or when a PO perceive a risk, he reacts emotionally or rationally (based on a specific stochastic human factor model) by changing behavior and, potential, moving to some other place (Bruzzone et al.2011). Indeed it is possible to calculate Origin/Destination (O/D) Matrixes in order to provide the PA with data aggregated at the level of the finest statistical zone available; in facts these results could be very useful for Verification & Validation of Data available in terms of O/D Matrixes by PA. In facts ST_CRISOM calculates the O/D Matrix as result of the daily activity of people by recreating the dynamic human presence over the different areas of the range of analysis during the simulation.
Simulated O/D matrix consider each single zone as an attraction/generation point and allows to conduct analysis devoted to correlated key factors such as the expected number of people respect different parameters such as, for instance, the number of Jobs, Schools and Household in each different zone. Simulated time is stepped into hours to collect simulation results for conducting risk analysis over the daily evolution, including morning and afternoon traffic peaks in working days and along weekends and other special occasions that can vary the people destinations.

h) Indicators: ST_CRISOM provides the user with different indicators for having a continuously updated overview of population feelings during the simulation. Such individual feelings can be aggregated at different level for better understanding the situation evolution. At the moment, ST_CRISOM consider the following main functions:

- Consensus in the local governance
- Trustiness (in the Alert System for floods)
- Fear

Such functions provide a quantitative feedback of the citizens “status” and their reaction to the different political choices on the different time-scales:

- short term behavior (during the flooding and during mitigation phase)
- long term behavior (i.e. trustiness in local governance after that a new floodway is completed)

i) Communication panel: the communication panel is available for the PA user and it allows to analyze the communication activity from Public Authorities to citizens. This is an emulator of the real communication channels and allow to the user to publish the alert on the following communication channels:

- Website
- Twitter
- Facebook
- SMS service
- Apps
- Road information panels
- Display on the bus stops

Each one of these communication channels will reach a certain percentage of population changing their feeling and modifying their behavior.
In order to increase the realism, ST_CRISOM reproduce the “crying wolf” phenomena: if too much information or too many weather warning are produces a decrease into the level of trustiness, and more and more people ignore the next warning about weather alert without modifying its behavior.

j) Budget: ST_CRISOM player have a budget and it is consumed based on the decisions and performed actions. Simulation consider use of these resources both in terms of money, people and work-hours; in facts at each action it is associated a cost, the number of people to complete it and the time required. These parameters could depend, or not, on weather conditions and other factors (e.g. strikes, demonstrations).

k) Damage estimation models: these functions allow to estimate the damage of the flooding according to the level and intensity within a specific area to the people present in such area when the flood occurred as well as to PoIs and other objects or entities

l) Decision Panel: this panel allow the user to undertake a set of strategic actions during the simulation such as, for instance:

- Improving the maximum level of the dike in a certain zone
- Realizing a new floodway

- Increase the number of panels in the road and in the bus stop in order to improve the communication among citizens
- Increase the number of rain gauges and increase the number of IoT (Internet of Things) device, for instance for improving the pre-alert phase
- Move the pumps from the bottom to the top of Public Buildings (i.e. hospitals)

ST_CRISOM allows to simulate the decisions along year time horizon to check the costs/benefits ration and the impact on safety and on population trustiness.

6. CONCLUSION

ST_CRISOM is a simulation solution originally designed for Public Administration (politician and analysts), but it is available also to be used by citizens for improving their understanding and active participation to public strategic decisions. Currently the focus is on preventive actions respect floods, therefore it is evident that this approach could be generalized over many different sectors. ST_CRISOM supports decision makers in estimating the impact of strategic decisions related to the hydrogeology of an area as well as on protective actions and flooding prevention projects considering a multi layer and multi resolution simulation; this approach is based on complex algorithms able to reproduce human and social behavior through simulation and these models have been already used into several other application fields.

ST_CRISOM allows the user to test the counterintuitive effects of different decisions in different domains such as economics, politics and environment with a particular focus on providing a direct feedback on the impact of such choices in terms of citizens consensus.

Currently, the research team is ongoing for calibrating ST_CRISOM algorithms with the Open Data from Genova Municipality respect flooding.

Indeed the ST_CRISOM multi-layer approach is promising and innovative, especially considering the evolution of ICT; in facts, this simulator combines modern data sources, Open Data, GIS information, human behavior modeling and Social Networks in a common multi-layer solution able to support crowdsourcing and to reproduce the effect of political decisions on population.

This approach is expected to generate in future several solutions able to serve as effective instruments for PA in order to improve planning and strategic decision making capabilities and to create mutual trustiness among citizens and authorities.

REFERENCES

Barry P., Koehler M. (2004) “Simulation in context: using data farming for decision support”, Proc. of the 36th Winter Simulation Conference, Dec., pp. 814-819

Baruah, T. D. (2012). “Effectiveness of Social Media as a tool of communication and its potential for technology enabled connections: A micro-level study”, International Journal of Scientific and Research Publications, 2(5), 1-10

Bromwich J.E. (2017) “Port Arthur Faces Harvey Flooding Disaster: ‘Our Whole City Is Underwater’”, The New York Times, August 30

Bruzzone A.G. Tremori A., Massei M. (2011) "Adding Smart to the Mix", Modeling Simulation & Training: The International Defense Training Journal, 3, 25-27, 2011

Bruzzone A.G., Cirillo L., Longo F., Nicoletti L. 2015, Multi-disciplinary approach to disasters management in industrial plants. Simulation Series, pp. 139.

Bruzzone A.G., M. Massei, M. Agresta, S. Poggi, F. Camponeschi, M. Camponeschi (2014a). "Addressing Strategic Challenges on Mega Cities Through MS2G”. 13th International Conference on Modeling and Applied Simulation, MAS, University of Bordeaux, France Sept. 10-12

Bruzzone A.G., Massei M., Longo F., Nicoletti L., Di Matteo R., Maglione G., Agresta M., (2015). Intelligent agents & interoperable simulation for strategic decision making on multicoalition joint operations. 5th International Defense and Homeland Security Simulation Workshop, DHSS 2015, pp. 72.

Bruzzone, A. G., Manetti, E., Perletto, P. (1998) “Object-oriented documentation from simulation for civil protection & industrial plant accidents shared directly on the web”, Simulation Series, 30, pp.168-173

Floridi, L.(2014).“Open data, data protection, and group privacy”, Philosophy & Technology, 27(1), 1-3.

Garton, L., C. Haythornthwaite & B. Wellman (1997). Studying online social networks. Journal of Computer-Mediated Communication, 3(1)

Heeks, R. (2001) “Understanding e-governance for development”, Manchester: Institute for Development Policy and Management

Howard, K. W., Israfilov, R. G. (2012). “Current problems of hydrogeology in urban areas, urban agglomerates and industrial centres”, Vol. 8 Springer Science & Business Media

Janssen, M., Charalabidis, Y., Zuiderwijk, A. (2012). “Benefits, adoption barriers and myths of open data and open government. Information+ systems management”, Vol 29 (4), 258-268

Jia, J., D. Liu, J. Tang, W. Wu, S. Zhao (2008). “Lack of Urban Disaster Prevention Land and Disaster Prevention Green Field Construciton: from perspective of Wenchuan Earthquake”, City Planning Review, 7, 009

Kassen, M. (2013) “A promising phenomenon of open data: A case study of the Chicago open data project”, Government Information Quarterly, 30(4), 508-513

Kitchin, R. (2014). "The data revolution: Big data, open data, data infrastructures and their consequences". Sage

Lankao, P. R., H. Qin, (2011). "Conceptualizing urban vulnerability to global climate and environmental change", Current opinion in environmental sustainability, 3(3), 142-149

Leichenko, R. (2011) "Climate change and urban resilience", Current opinion in environmental sustainability, 3(3), 164-168

Massei, M., S. Poggi, M. Agresta & A. Ferrando (2014). "Development planning based on interoperable agent driven simulation". Journal of Computational Science, 5(3), 395-407.

Ören T., Longo F., (2008). Emergence, anticipation and multisimulation: Bases for conflict simulation. 20th European Modeling and Simulation Symposium, EMSS 2008, pp. 546.

Rimlinger, G. V. (1971) "Welfare policy and industrialization in Europe, America and Russia", John Wiley & Sons, NYC

Rossetti, R. J., Almeida, J. E., Kokkinogenis, Z., Gonçalves, J. (2013) "Playing transportation seriously: Applications of serious games to artificial transportation systems", IEEE Intelligent Systems, 28(4), 107-112

Schirmer, M., Leschik, S., Musolff, A. (2013). "Current research in urban hydrogeology–a review", Advances in Water Resources, 51, 280-291

Trusov, M., R. E. Bucklin, K. Pauwels (2009). "Effects of word-of-mouth versus traditional marketing: findings from an internet social networking site", Journal of marketing, 73(5), 90-102

LIFE CYCLE ASSESSMENT OF A SPREADABLE CREAM MADE FROM PARMESAN CHEESE

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ABSTRACT

The aim of this work is to evaluate the environmental impact of a spreadable cream based on Parmigiano Reggiano by means of the Life Cycle Assesment methodology (hereinafter referred to as LCA methodology), and to minimize its environmental impact through a sensitivity analysis. The considered product is a spreadable cream consisting of two ingredients: grated Parmigiano Reggiano and organic extra virgin olive oil.

Two main packaging materials can be used and have been considered in the analysis: jars made of PET and glass jars. The LCA analysis was carried out using SimaPro 8.2 software. Primary data have been obtained by interviewing the owner of the dairy company, which produces the analyzed product, while secondary data have been taken by the Ecoinvent 3.2 database and by using specific literature.

The impact method is based on the Environmental Product Declaration (EPD) standard: the impact categories considered are: (i) acidification, (ii) eutrophication, (iii) Global Warning Potential (GWP 100a), (iv) Photochemical oxidation, (v) Ozone layer depletion (vi) Abiotic depletion.

The results show that the most influential phase is the Parmigiano Reggiano's production with impacts ranging from 58% to 92% of all the considered categories. Some solutions to improve the environmental impact of the product have finally been reported.

Keywords: LCA, cheese, cream, olive oil, sustainable production, environmental assessment.

1. INTRODUCTION

Life Cycle Assessment (LCA) is a process that allows you to estimate potential environmental impacts associated with a process or activity product by analyzing the entire production process "from cradle to grave" or parts of it "from cradle to gate".

It quantifies the consumption of matter, energy and emissions in the environment and identifies and evaluates the opportunities to reduce the associated impacts.

It consists of four basic phases:

- Definition of the goal and scope of the LCA
- Life cycle inventory analysis (LCI) phase
- Life cycle impact assessment (LCIA) phase
- Interpretation phase

Frequently associated to these four steps there is also a reporting and critical review of the LCA.

The main rules for applying the LCA method are:

ISO 14044. Environmental Management – Life Cycle Assessment. Requirements and Guidelines.

ISO 14040. Environmental Management – Life Cycle Assessment. Principles and Framework.

The first one is of a more general nature that outlines the principles and describes the structure of an LCA; the second one reports the requirements and guidelines, and (it) is the main support for the practical application of a lifecycle study.

From 2006 to nowadays several other international rules and standards have been realized (ISO 14021, ISO 14024, ISO 14025) but among them especially the ILCD handbook is of particular interest. In response to the commitments in the Integrated Product Policy (IPP) communication of the European Commission, the Joint Research Centre prepared the ILCD handbook to meet suggestions made by the European Commission in the Integrated Product Policy (IPP) communication. The ILCD Handbook was published in 2010. It is based on ISO 14040/44, but provides much more detailed technical guidance. The ILCD Handbook contains detailed descriptions and requirements in order to reduce flexibility in choices and to support consistency and quality assurance of LCA results.

Based on this acknowledgement to perform an environmental assessment of products, especially in the food sector, an increased attention is attributed to certification and to defining standard methods for the food product evaluation.

Well known in the food sector is the Environmental Product Declaration (EPD) standard. Based on this standard it is possible to certify for example a Food Product by evaluating the impact associated to all its phases along its supply chain. Aim of this standard is to compare products with the same sector and provide the customers with a certified evaluation on six different environmental impact categories.

For each category of products there is a specific Product Category Rule (PCR), which has to compliant to the EPD standard. In 2017 there are 41 PCR's in "Food & Agricultural Products", which are frequently updated and available on the website www.environdec.com/PCR.

The LCA of food products is particularly complex because of the several/various phases of the food supply chain (Agricultural, postharvest, processing, packaging, distribution, consumption, end of life) and due to the presence of losses and waste in each of these phases (Manfredi and Vignali, 2014; Cellura et al, 2012).

Commonly some phases are neglected or less investigated by being excluded from the system boundaries. In the food packaging phase, e.g. the evaluation of the equipment consumptions have been investigated only sometimes (Manfredi and Vignali, 2015; Bertolini et al., 2016). Furthermore, the examination of Food waste is often not considered, despite of its high impact on the environmental profile of food products (Manfredi et al., 2015; Mosna et al., 2016).

Based on these premises, the aim of the paper is to evaluate the environmental impact of a spreadable cream based on Parmigiano Reggiano by means of the LCA methodology following the EPD standard, and to minimize the environmental impact through a sensitivity analysis. The considered product is a spreadable cream consisting of two ingredients: grated Parmigiano Reggiano and organic extra virgin olive oil. The remainder of the article is composed as follows: The second chapter describes the state of art of LCA evaluation in the field of milk cheese and vegetable oil. In the third chapter, all the inventory needed for an LCA evaluation will be analyzed. Section 4 summarizes the main results obtained; section 5 discuss the main results while the conclusion section shows the main aspect of the work and the future researches.

2. LCA STUDIES FOR CHEESE AND EXTRA VIRGIN OLIVE OIL

The analyzed product being composed by Parmigiano Reggiano cheese and extra virgin oil, this chapter will evaluate the state of art of LCA studies for dairy products and extra virgin oil.

As far as LCA studies of dairy products are concerned, the literature mentions some articles, of which the majority were performed d in Europe and some in North America. A summary of the most interesting for our scope are reported below.

Kim et al., 2013 analyzed the environmental impact of cheddar cheese and mozzarella from cradle to grave, using several impact methods and subsequently several impact categories. Results showed that the raw milk production is the main source of influence in all the considered impact categories, both for mozzarella (on average 60%) and Cheddar cheese (on average 80%).

Dekic et al., 2014 examined some dairy products (milk, yogurt, cheese, cream and butter) from birth to death, throughout their life span using the CCALC 2013 impact method. They use five impact categories, showing how the raw milk is the main source of impact, although impossible to generalize said impact for all the dairy products. As far as the GWP is concerned, the impact values vary from 6.73 to 9.47 kg/CO2 eq. per kg of product.

Finnegan et al, 2017 studied other dairy products such as whole milk, skimmed mild, semi skinned milk, butter, cheese, cream, milk powders and whey powders from cradle to gate using IPCC impact Method, with only GWP 100 as an indicator. They found a minimum of 6.7 kg/CO2 eq. per kg of product. In the case of cheese, the authors found that raw milk production counts about 93% of the environment impacts and that a possible way to reduce them is to optimize the use of natural resources (water and energy).

Van Middelaar et al., (2011) analyzed the production of semi-hard cheese in the Netherlands with a cradle to gate approach using the IPCC Impact method and GWP100 as impact category. They discovered an impact of 8.5kg of CO2 eq. per kilogram of the complete product. In this case, the cultivation of concentrated ingredients and the raw milk production are the two main sources of environmental impact.

Berlin (2002) investigated a semi-hard cheese in Sweden, using the IPP and CML impact methods and also adopting the Nordic guidelines. As explained by other authors she observed that the main impact is to the result of the raw milk production and that the best solution to reduce the environmental impact was to decrease the waste during the collection and the process.

In the USA, Milani et al. (2011) found in their review that in order to reduce the environmental impact of dairy processing it is necessary to diminishing the use of the water and also to optimize the recovery system of the grey water.

Brokema and Kramer (2014) discovered that if the impact of the soil cultivation was accounted for, the total impact of the cheese production increases. In their study, which was performed in the Netherlands and considers a cradle to grave approach, the impact in GWP of a skimmed milk and semi-cured cheese was 8.67 kg/CO2 eq. per kg of product.

In Portugal, Gonzales-García et al. (2013) defined the value of GWP for a Galician cheese as 10.44 kg/CO2 eq. per kg of the product. Additionally, they demonstrated that the environmental impact could be reduced if the processing waste was reused to produce other products, instead of being landfilled together with grey water.

Flysjo et al. (2014) introduced the concept that a milk concentration could be useful to reduce the impact of dairy products. Very important is also the waste of product along the whole supply chain and in particular at a household level. Each innovation to reduce the waste will give a positive contribution to the environmental impact of such product.

Doublet et al. (2013) showed that in the cheese production in Romania the most impactful phase is the raw milk production, but also the energy consumption could have a significant effect in some impact categories.

As far as olive oil is concerned, several studies have been performed by private companies to certify their products according to the EPD standard, especially in Italy. Monini (Monini, 2012), Oassi and Castillo Canena obtained an EPD certification for extra virgin olive oil with values of GWP between 2.2 to 4.3 kg/CO2 eq. per kg of product.

Among the scientific studies, Avramides and Fatta (2008) showed with a cradle to gate approach realized in Cyprus that the main environmental impact lies within the agricultural phase. Particularly the inorganic fertilizer, the olive oil transformation and the landfill of liquid effluents are the hot spots of the entire process.

Salomone et al. (2010) underlined the importance of the choice of Functional unit in the case of an olive oil assessment. It is also very difficult to collect reliable data in this sector due to the different treatment applied by the producers. Therefore, a consistent variability in the data is present. They found overall 4.305 kg/CO2 eq. per kg of product, considering also the impact of nitrogen compounds.

One year later (2012), Salomone and Ioppolo also performed a sensitivity analysis in order to demonstrate a way of reducing the environmental impact of olive oil production. They proved the anticipated necessity of using Olive Mill Pomance (OMP) and Olive Met Wastewaters (OMW) instead of Olive Wet Pomance (OWP).

Busset et al. (2012) performed an LCA analysis in France, by using Recipe midpoint and endpoint. They reported a high value of GWP (6.6 kg/CO2 eq. per kg of product), mainly due to the use of fertilizer and to phytosanitary treatment.

In Greece (2014), Tsarouhas et al. found that in Italy only the cultivation phase for olive oil has an impact of 1.08 kg/CO2 eq. per kg of product. Nevertheless, the only way to reduce the impact in their view was to optimize the management of grey water, which is produced by the oil skin during the olive oil production.

Based on this analysis of peculiarities of the existing studies, a LCA of a spreadable cream made from parmesan cheese and extra virgin olive oil will be demonstrated in the following sections.

3. LCA OF SPREADABLE CREAM MADE FROM PARMESAN CHEESE AND EXTRA VIRGIN OLIVE OIL.

3.1. Goal and scope definition

According to the prescription of ISO 14040 and ISO 14044 the objectives of the analysis, the choice of the functional unit, the system boundaries and the assumptions used for the analysis are defined in the goal and scope definition.

The goal of the study is to assess the environmental impact, by means of an LCA approach, of a spreadable cream made from parmesan cheese and extra virgin olive oil, which can be packaged in a glass or polyethylene terephthalate (PET) jar.

The functional unit chosen for the LCA is a unit of 290g of this cream packaged both in glass and in PET.

As far as the system boundaries definition is concerned, the authors have chosen to have a cradle to grave approach, considering both the production of raw material and the end of life of the product and the packaging materials.

The system boundaries are reported in Fig. 1.

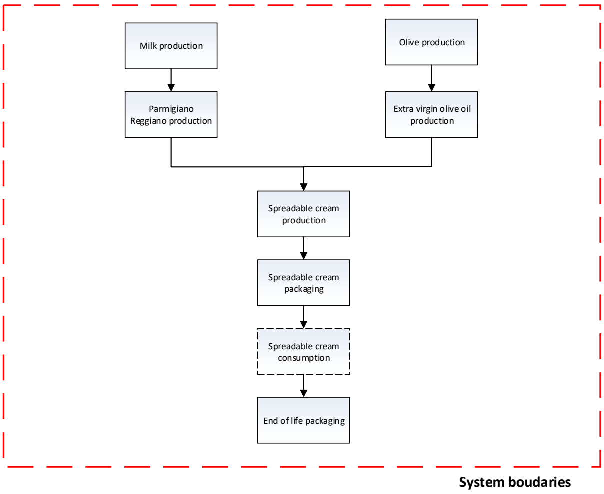

Fig.1: System boundaries of the analyzed product

The first phases of the process include the production of the milk and of the olives. As regards the olive oil, the company delivering the oil for the cream production decides to cultivate and crop the olives in Italy.

The olive grove is made of plants cultivated partially with a traditional extensive system and partially with intensive systems. The difference between the two systems is connected to the density of the plants, which is higher in the case of intensive systems.

The process of **extra virgin olive oil** production is composed of:

1. Olive grove preparation: trenching, weeding, tillage and harrowing, followed by the creeping thistle planting;
2. Olive grove cultivation: this phase is before the plant is productive and it needs water, fertilization, and phytosanitary treatments;
3. Olives' crop: once the plants have reached their maturations, they start to be productive and give olives, which can crop manually or automatically.
4. Olives' transport to oil mill: olives are collected in bins and then sent to an oil mill
5. Oil milling: the analyzed process is continuous and consists of:
    a. Olive storage in bins
    b. Weighting
    c. Defoliation
    d. Cleaning with cold water
    e. Olives pressing

f. Kneading operation
g. Extraction of oil and olive pomace
h. Storage and soil deposition of pomace
i. Centrifugal oil separation
j. Oil storage in stainless steel tank
k. Oil filtration with plate system

6. Bottling and labelling of extra virgin olive oil in glass bottle or metallic jar.
7. Secondary packaging of glass bottles or metallic jars
8. Transport of packaged extra virgin olive oil to spreadable cream production site

In regards to Parmigiano Reggiano, a previous LCA studies has been performed (Caseificio Caramasche Soc. Coop. 2014). In the analyzed process local milk producers transport the raw milk to the cheese production site every day in the morning and in the afternoon. To obtain this seasoned hard cured cheese, several activities will be performed in the milk processing company. As indicated by the flow described below, the process can last until 24 months (due to the seasoning of this particular product) and the final product has a substantial weight decrease in respect to the weight before the seasoning process.
Parmigiano Reggiano production begins with milk collection, which is done twice a day: once in the evening, and once in the morning, after milking.
The whole milk of the evening milking is left to rest overnight. Overnight, the fatty part of the milk, the cream, floats naturally to the surface, and is then used later to make butter. The milk remaining below the cream layer is the skimmed milk.
Early in the morning, this mixture of milk are inserted in the copper cauldrons with their typical upturned cone shape. In this very delicate phase, only the skimmed milk is poured into the vats, without the cream. At this stage, the whole milk, delivered to the cheese factory after the morning milking, is also added to the cauldrons.
The proportions of skimmed and whole milk are determined day by day. Milk is then turned into Parmigiano Reggiano in 3 separate phases:

- Heating
- Curd Breaking
- Cooking

Heating: Once in the cauldron, the milk is heated slowly. During this process, the whey starter culture is added, a liquid mixture rich in lactic ferments obtained from the processing of the previous day's milk. The milk is heated to around 30° C and then the calf rennet is added. The mixture is stirred carefully then left to rest for 8-10 minutes to allow for natural coagulation. This produces the curd.
Curd breaking: In this phase the curd is broken into small granules, and the cheese maker checks that the curd has reached the right density. A special tool, the "spino", is used to break the curd.
Cooking: the mixture is then heated to 55° C. At this temperature, the micro-granules lose their humidity and sink to the bottom of the cauldron. After around 50 minutes, the compact mass can be removed from the cauldron. Using a wooden paddle, the solidified cheesy mass is removed and wrapped in muslin. The mass is ready to be cut into 2 equal parts. Each half is placed in a plastic mold, the buckle known as “fascera”, and pressed down with a Teflon weight.

Every wheel produced during the day is turned four times; the first and second time, the wet muslin is replaced with a dry one to absorb more humidity.
The third time it is turned, the muslin cloth is taken out. The wheel is then wrapped in a special belt issued by the Parmigiano Reggiano Consortium.
The next morning, the wheels are placed in a special steel belt that gives them their rounded shape.
Packaging and sale. At the end of the maturation process, which lasts between 12 and 36 months or more, the Parmigiano Reggiano is ready to be enjoyed by consumers.

Spreadable cream production
The first phase of the process involves the crust removal from the Parmigiano Reggiano cheese as well as the cheese cutting in portions, which can be grated.
The cheese is grated using several types of sieves, in function of the seasoning and consistency of the product.
The grated product is then mixed with the extra virgin olive oil; to realize the specific dough in a specific kneading machine. This spreadable cream is produced by mixing 70% of Parmigiano Reggiano Cheese with 30% of extra virgin olive oil.
This homogeneous dough is then filled in glass or PET jar and capped with a plastic (for PET jar) or metallic (for glass jar) cap. Up to this point, due to the low level of production of this spreadable cream, these activities will be performed manually by a company worker.
Finally, all the jars are checked and subsequently labelled by means of a manual labelling machine.
More details about the flow and the production process are given by the diagram in Fig. 2 and Table 1.

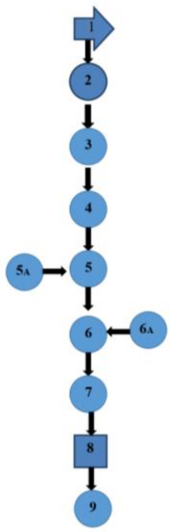

Fig.2: Flow of spreadable cheese production process

Table 1: phases of production process of spreadable cream.

Phase	Description	Quantity	Waste	Time
1	Transport of Parmigiano	6 wheels	none	2 min
2	Cutting wheel	6 wheels	3 kg/wheel	2min/wheel
3	Grater	6 portioned wheels	none	2min/wheel
4	Sieving	205 kg	5 kg	3 min
5	Mixture	250 kg	none	3 min
6	Filling	900 jars	none	1 s/jar
7	Capping	900 jars	none	3 s/jar
8	Checking	900 jars	none	1 s/jar
9	Labelling	900 jars	none	6 s
5a	Oil adding	50 kg	none	1 min
6a	sterilization of jars	900 jars	none	3 s/jar

3.2. Inventory Analysis

The first aspect to be underlined is that both primary and secondary data have been used for this phase.
Primary data was collected by the spreadable cream production company, whereas secondary data have been taken from the Ecoinvent 3.2, other databases available in SimaPro 8.2 software and from scientific literature.
Starting with the raw milk production the first series of data is connected to the pre-lactation activities of cows. These activities are considered to last for 3 years.
Table 2 shows the inventory data related to this process.

Table 2: inventory data of pre-lactation phase

	Unit	Quantity	Reference	Database
Pre-lactation				
Inputs				
Alfalfa	kg/cow	12	primary data	Alfalfa-grass mixture, Swiss integrated production {GLO}| market for | Alloc Def, U
Concentrated feeds	kg/cow	12	primary data	Maize, at farm/IT Economic
Water	kg/cow	60	primary data	Tap water {Europe without Switzerland}| market for | Alloc Def, U
Electricity	kwh	0,4	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U
Output				
Manure and sewage	kg/cow	34	primary data	

The next phase evaluated in the inventory is the milk production, which has a reporting period of 10 years. This is in fact the lactation period, which we assumed for a cow.
Several aspects have been considered and reported in table 3. 28 kg of daily milk production has been assumed for a cow, which is raised following the specific Parmigiano Reggiano cheese disciplinary proceedings.
Some allocations have been made considering the economic value of each produced good.

Table 3: inventory data of raw milk production phase

	Unit	Quantity	Reference	Database
phase of milk production	kg/day	28		
Inputs				
Alfalfa	kg/cow* day	8	primary data	Alfalfa-grass mixture, Swiss integrated production {GLO}| market for | Alloc Def, U
Hay	kg/cow* day	8	primary data	Hay, Swiss integrated production, extensive {GLO}| market for | Alloc Def, U
Maize	kg/cow* day	16	primary data	Maize, at farm/IT Economic
	kg/cow* day	75	primary data	Water, unspecified natural origin, IT
Equipment cleaning	kg/cow* day	2	primary data	Tap water {Europe without Switzerland}| market for | Alloc Def, U
Cooling of milk	kg/cow* day	28	primary data	Tap water {Europe without Switzerland}| market for | Alloc Def, U
Electricity	kWh	0,4	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U
transport to cheese factory	Kg*km	252	primary data	Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO3, carbon dioxide, liquid refrigerant, freezing {GLO}| market for t
Output				
Manure and sewage	kg/cow* day	50		

From the milk processing we obtained the data to evaluate the cheese production in the dairy production site. The inventory of the cheese production process is reported below in table 4.

Table 4: inventory data of parmesan cheese production phase

	Unit	Quantity	Reference	Database
Skimming in basins	kg	4400	primary data	
Inputs				
milk	kg	4400	primary data	
Draining pump	kwh	0,51	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U
Output				
Biologic purifier	kg	5200	primary data	Water, IT
cream	kg	704	primary data	
skimmed milk	kg	3696	primary data	

	Unit	Quantity	Reference	Database
boiling in double bottoms	kg	1100		
Inputs				
whole milk	kg	550	primary data	
skimmed milk	kg	550	primary data	
Fuel oil	l	6.25	primary data	Heavy fuel oil {Europe without Switzerland}| market for | Alloc Def, U
celaning	kg	1100	secondary data	Water, decarbonised, at user {GLO}| diethyl ether production | Alloc Def, U
Output				
Biologic purifier	kg	438	primary data	Water, IT

	Unit	Quantity	Reference
Rest of the wheels	wheel of parmigiano	1	
Inputs			
Curd extraction	kg/wheel	40	primary data
wheel after the rest	kg/wheel	39	primary data
Linen sheet	g/wheel	125	secondary data
Teflon mold	kg/mold*wheel	2	secondary data
Zinc mold	kg/mold*wheel	1	secondary data
Wooden boards	kg/wheel	0.25	secondary data

	Unit	Quantity	Reference	Database
Brine bath	wheel of parmigiano reggiano	1		
Inputs				
water	m^3	0.5	primary data	Tap water {Europe without Switzerland}| market for | Alloc Def, S
salt	kg/wheel	2.5	secondary data	Sodium chloride, production mix, at plant, dissolved RER
gantry crane	kwh	1.955	secondary data	Electricity, low voltage {IT}| market for | Alloc Def, U

After the wheels production of parmesan cheese, these wheels are storage in specific warehouses for at least 12months. During this period, the wheels are cleaned by means of a specific robot.

Table 5: inventory data of parmesan cheese seasoning

	Unit	Quantity	Reference	Database
Phase of seasoning	1 wheel of parmigiano reggiano	1		
Input				
Electricity (winter)	kWh	22.97	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U
Electricity (summer)	kWh	68.926	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U

Based on the previous reported inventory we have evaluated the inventory for the production of a finished wheel of a Parmigiano Reggiano cheese. The weight of a 12 months seasoned wheel, ready for the market, has been considered of 39kg.

Table 6: summary of inventory data of parmesan cheese

	Unit	Quantity	Reference
production of a wheel of parmesan cheese	wheel of parmesan cheese	1	
Inputs			
Milk production	l	550	primary data
boiling nei doppi fondi	l	550	primary data
bagno in salamoia	days	20	secondary data
phase of rest	h	24	secondary data
seasoning	months	12	secondary data

After this phase, the inventory connected to the production of the spreadable cream has been reported.

Table 7: inventory data of spreadable cream production

	Unit	Quantity	Reference	Database
Cutting of a wheel	jar	1		
Input				
electricity	kwh/jar	0.0048	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U

	Unit	Quantity	Reference	Database
Grater	jar	1		
Input				
electricity	kwh/vas	0.02	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U

	Unit	Quantity	Reference	Database
Sieving	jar	1		
Input				
electricity	kwh/jar	0.014	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U

	Unit	Quantity	Reference	Database
mixture	jar	1		
Input				
Extra virgin oil	kg	0.0945	Secondary data	EPD monini group
Grated cheese	kg	0.203	Primary data	
electricity	kwh/jar	0.014	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U

Table 8: summary of inventory data of spreadable cream production

	Unit	Quantity	Reference
Production process spreadable cream	jar	1	
Inputs			
cut della wheel	kg	0.203	primary data
gratuggia	kg	0.203	primary data
sieve	kg	0.203	primary data
mixture	kg	0,300	primary data

After the spreadable cheese preparation, this product can be filled in glass or PET jar, thanks to the same equipment. To complete the packaging phase, the capping, labelling and secondary packaging are needed.

Table 9: : inventory data of spreadable cream packaging

	Unit	Quantity	Reference	Database
Filling	jar	1		
Input				
filling	kwh/h	0.0055	primary data	Electricity, low voltage {IT}| market for | Alloc Def, U

	Unit	Quantity	Reference	Database
Glass jar packaging	g	1		
Inputs				
jar di glass	g	174	primary data	Packaging glass, white {GLO}| market for | Alloc Def, U
Capping	g	8	primary data	Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| market for | Alloc Def, U
Labelling	g	2	primary data	Paper, bag and sack, unbleached kraft, average production, at mill/kg/RNA
Secondary packaging	g	1,25	primary data	Paper, bag and sack, unbleached kraft, average production, at mill/kg/RNA

	Unit	Quantity	Reference	Database
PET jar packaging	g	1		
Inputs				
jar PET	g	34	primary data	Polyethylene terephthalate, granulate, amorphous {GLO}| market for | Alloc Def, U
Capping	g	6	primary data	Polyethylene terephthalate, granulate, amorphous {GLO}| market for | Alloc Def, U
Labelling	g	2	primary data	Paper, bag and sack, unbleached kraft, average production, at mill/kg/RNA
Secondary packaging	g	1.8	primary data	Kraft paper, bleached {GLO}| market for | Alloc Def, U

Both PET and glass jars are then sent to the market using similar transports, but in the case of PET jars, they are sold in Italy, while Glass jars are sold abroad. Inventory analysis has considered an average distance for the two products.

Table 10: inventory data of spreadable cream transport

	Unit	Quantity	Reference	Database
Transport of PET jars	Filled jar	1	primary data	
Input				
jar di elisisr in PET	kg.km	100.8	primary data	Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO3, R134a refrigerant, cooling {GLO}| market for | Alloc Def, S

	Unit	Quantity	Reference	Database
Transport of glass jars	Filled jar	1	primary data	
Input				
jar di elisisr in PET	kg.km	202.3	primary data	Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO3, carbon dioxide, liquid refrigerant, cooling {GLO}| market for | Alloc Def, S

Finally, the end of life of packaging materials has been considered, by adopting a landfilling process to be conservative.

Table 11: inventory data of packaging end of life

	Unit	Quantity	Reference	Database
Glass jar end of life	jar	1		
Inputs				
transport to landfill of jar glass	kg.km	9.3	primary data	Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO3, carbon dioxide, liquid refrigerant, cooling {GLO}| market for | Alloc Def, S
glass jar	g	174	primary data	Landfill of glas/inert waste EU-27
cap	g	8	primary data	Landfill of iron metals EU-27
etichetta	g	2	primary data	Landfill of paper waste EU-27
packaging secondary	g	1,25	primary data	Landfill of paper waste EU-27

	Unit	Quantity	Reference	Database
PET jar end of life	jar	1		
Inputs				
transport to landfill of PET jar	kg.km	2.3	primary data	Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO3, R134a refrigerant, cooling {GLO}| market for | Alloc Def, S
PET jar	g	34	primary data	Landfill of plastic waste EU-27
cap	g	6	primary data	Landfill of iron metals EU-27 U
Labelling	g	2	primary data	Landfill of paper waste EU-27
secondary packaging	g	1.8	primary data	Landfill of iron metals EU-27 U

3.3. Method of impact assessment

The data collected in the inventory analysis are the basis for the impact assessment phase whose aim is to evaluate the potential environmental impact of the system (ISO 14040, 2006) caused by effluent emissions, releases into the environment and resources consumption.

The impact analysis was carried out using the EPD (2013) method.

Impact values were calculated at midpoint level for 6 impact categories: (i) Acidification (fate not incl.), (ii) Eutrophication, (iii) Global warming (GWP100a), (iv) Photochemical oxidation, (vi) Ozone layer depletion (ODP), and (v) Abiotic depletion.

4. LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The first analyses, which have been performed, are related to the two main ingredients of the spreadable cream, i.e.: extra virgin olive oil and parmesan cheese. Table 11 and 12 shows the related impacts.

Table 11: LCA of 1 kg of extra virgin Olive oil

Impact category	Unità	Totale	Coltivazione	produzione olio	Confezionamento e packaging	trasporto
Acidification (fate not incl.)	kg SO2 eq	3,21 E-03	0,000438	0,000042	0,002693826	0,000032
Eutrophication	kg PO4--- eq	4,20 E-03	0,003525	0,000178	0,000240439	0,000258
Global warming (GWP100a)	kg CO2 eq	3,78 E+00	3,078	0,238	0,45132049	0,008
Photochemical oxidation	kg C2H4 eq	1,72 E-02	0,016	0,000948	0,000162014	0,00013
Ozone layer depletion (ODP)	kg CFC-11 eq	1,89 E-07	0,000000116	0,000000037	2,19417E-08	0,000000014
Abiotic depletion	kg Sb eq	4,19 E-05	8,82808E-06	4,34952 E-07	1,49509E-05	1,76562E-05

Table 12: LCA of 1 parmesan cheese wheel

Impact category	Unità	Totale	litro di latte	boiling nei doppi fondi	bagno in salamoia	fase di rest	stagio natura
Acidification (fate not incl.)	kg SO2 eq	1,21 E+01	11,91678421	1,59E-02	0,006144422	-0,000880577	0,202350132
Eutrophication	kg PO4--- eq	7,85 E+00	7,824706692	1,81E-03	0,000571436	-0,000435546	0,01871616
Global warming (GWP100a)	kg CO2 eq	8,26 E+02	777,3028463	1,50E+00	1,331339195	-0,138433557	46,19820759
Photochemical oxidation	kg C2H4 eq	1,03 E-01	0,091839506	8,28E-04	0,000331539	-3,67177E-05	0,010418405
Ozone layer depletion (ODP)	kg CFC-11 eq	3,29 E-05	2,31E-05	3,75E-06	1,53546E-07	-7,44003E-09	5,91879E-06
Abiotic depletion	kg Sb eq	1,10 E-03	9,72E-04	-1,39E-05	3,99793E-06	-2,65552E-07	0,000137722

Using then all the inventories previously described, it has been possible to discover the total impact of the spreadable cream, packaged in glass and in PET.
Tables 13 and 14 and figures 3 and 4 show the total impacts for all the considered categories and the relative impacts of each of the considered phases.

Table 13: LCIA of 1 glass jar of spreadable cream

Impact categories	Unit	Total	Parmesan wheel production	Extra virgin olive oil	Spreadable cream production	Glass jar packaging	Filled jar transport	Glass jar transport to landfill	Landfill
Acidification (fate not incl.)	kg SO2 eq	7.396E-02	6.319E-02	7.178E-03	5.791E-05	2.040E-03	7.177E-04	7.599E-04	1.719E-05
Eutrophication	kg PO4--- eq	4.420E-02	4.084E-02	2.915E-03	5.356E-06	1.580E-04	1.131E-04	1.198E-04	5.342E-05
Global warming (GWP100a)	kg CO2 eq	6.118E+00	4.300E+00	1.276E+00	1.322E-02	2.662E-01	1.246E-01	1.319E-01	5.093E-03
Photochemical oxidation	kg C2H4 eq	1.136E-03	5.381E-04	4.418E-04	2.981E-06	1.032E-04	2.357E-05	2.496E-05	1.635E-06
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	2.990E-07	1.714E-07	5.325E-08	1.694E-09	2.795E-08	2.167E-08	2.294E-08	6.830E-11
Abiotic depletion (optional)	kg Sb eq	1.446E-05	5.722E-06	6.910E-06	3.941E-08	4.943E-07	6.271E-07	6.640E-07	1.410E-10

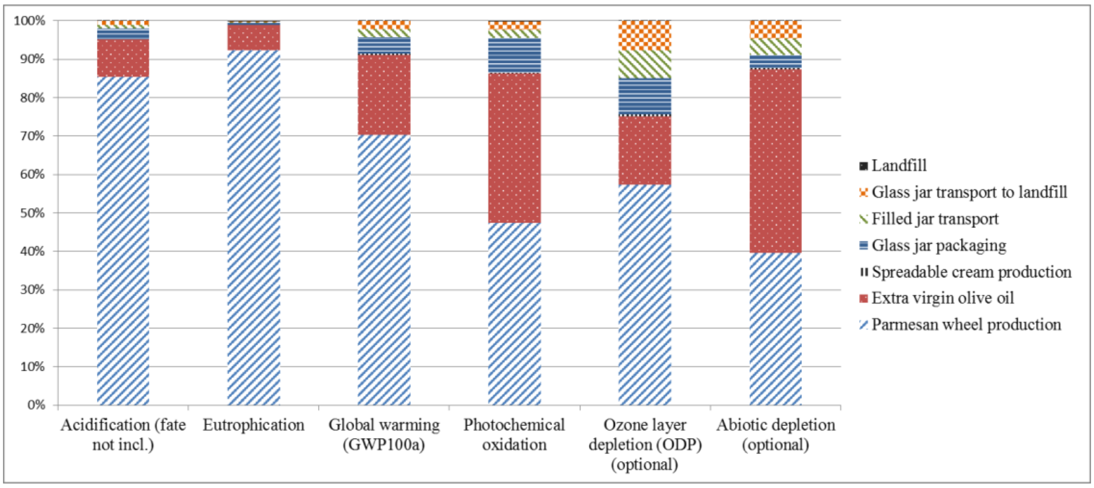

Fig.3: Relative impact of each phase of spreadable cheese packaged in glass jar

Table 14: LCIA of 1 PET jar of spreadable cream

Impact categories	Unit	Total	Parmesan wheel production	Extra virgin olive oil	Spreadable cream production	PET jar packaging	Filled jar transport	PET jar transport to landfill	Landfill
Acidification (fate not incl.)	kg SO2 eq	7.185E-02	6.319E-02	7.178E-03	5.791E-05	9.947E-04	3.579E-04	5.965E-05	1.028E-05
Eutrophication	kg PO4--- eq	4.394E-02	4.084E-02	2.915E-03	5.356E-06	9.322E-05	5.640E-05	9.399E-06	2.069E-05
Global warming (GWP100a)	kg CO2 eq	5.885E+00	4.300E+00	1.276E+00	1.322E-02	2.101E-01	6.751E-02	1.125E-02	5.787E-03
Photochemical oxidation	kg C2H4 eq	1.055E-03	5.381E-04	4.418E-04	2.981E-06	5.698E-05	1.176E-05	1.960E-06	1.432E-06
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	2.917E-07	1.714E-07	5.325E-08	1.694E-09	1.223E-08	4.541E-08	7.568E-09	1.139E-10
Abiotic depletion (optional)	kg Sb eq	1.387E-05	5.722E-06	6.910E-06	3.941E-08	8.377E-07	3.130E-07	5.216E-08	2.109E-10

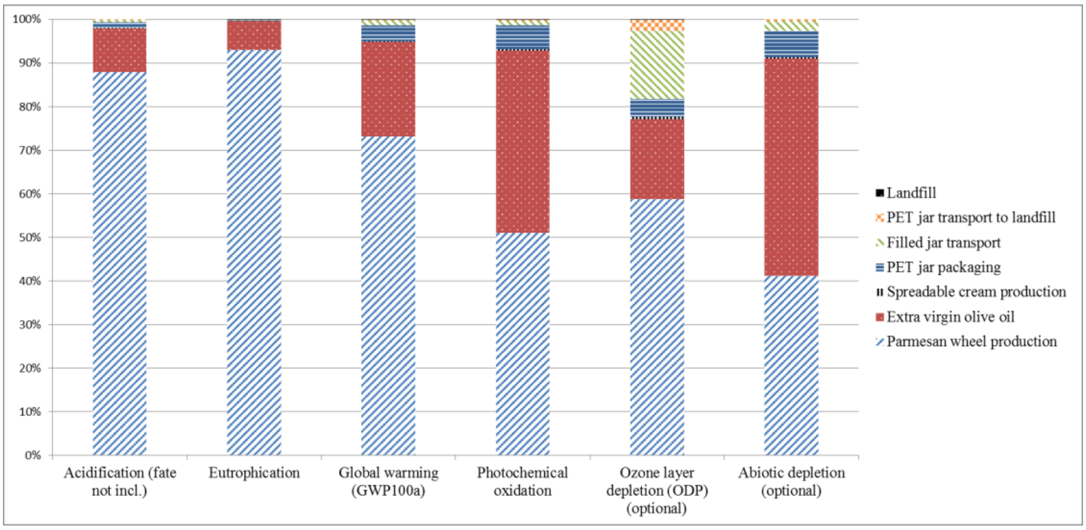

Fig.4: Relative impact of each phase of spreadable cheese packaged in PET jar

5. DISCUSSION AND SENSITIVITY ANALYSIS

Some sensitivity analyses have been performed in order to understand which phase could be improved in order to have the main benefit from an environmental point of view:

- An environmental impact analysis of the pre-lactation phase has been performed by replacing 50% of the amount of corn used with other feeds. This new scenario has been then compared to the present situation.
- An analysis was made by increasing the productivity of a cow from 28l, as it is currently done, to produce 30 l.
- An environmental impact analysis has been done by valorizing more the by-products (cream).
- Another analysis was done by replacing all the electricity with the photovoltaic energy and the fuel oil used with methane.
- Comparative analysis replacing all electrical and photovoltaic energy for the current production process of the spreadable cream.
- By reducing the weight of the glass jar by 20%, we made a comparative analysis of the environmental impacts due to the different weights of the jar.
- Another comparative analysis of environmental impacts was made by replacing the PET jar with one of bioplastics (PLA).

From an environmental point of view, all these changes have given benefits, but most of them have also an important economic impact, which has to be assessed.

6. CONCLUSIONS

Starting from the process definition of a spreadable cream of Parmesan cheese packaged in jar, we were able to quantify the environmental impact of two products, throughout the life cycle. As can be seen from the analysis, the stage of production of raw milk is most impactful, followed by the impact due to olive oil production and by the impact due to the packaging (mainly for the jar of glass).

To reduce the environmental impact connected to the analyzed product, particular attention should be paid to the stages of cow breeding and milking. Some effective active to improve the actual process could be:

- Using less impacted maize feed then that currently used (reduce the use of corn and increase the amount of other feeds)
- Increasing the cow productivity, by means of decreasing the prelate phase and by increasing the lactation rate and increasing the daily milk production (changing the breed of cows)
- Optimizing the amount of food to give to animals. In fact, less food could be given to the cows, without decreasing the productivity.
- valorizing the by-products (cream and whey); this would decrease the impact of a wheel of Parmigiano Reggiano.
- Use methane instead of fuel oil for boiling the curd
- Replace all electricity with photovoltaic energy.
- Assess the technical feasibility of reducing the current weight of the glass jar by 20%
- Use a bioplastic jar (PLA) as thye jar packing materials.

REFERENCES

Avraamides M., Fatta D., (2008). Resource consumption and emissions from olive oil production: a life cycle inventory case study in Cyprus, Journal of Cleaner Production, 16 (7), pp. 809-821.

Berlin, J. (2002). Environmental life cycle assessment (LCA) of Swedish semihard cheese, International Dairy Journal, 12, pp. 939-953.

Berlin, J. (2002). Environmental life cycle assessment (LCA) of Swedish semi-hard cheese, International Dairy Journal, 12, pp. 939-953.

Bertolini, M., Bottani, E., Vignali, G., Volpi, A. (2016). Comparative Life Cycle Assessment of Packaging Systems for Extended Shelf Life Milk. Packaging Technology and Science, 29 (10), pp. 525-546.

Brokema R., Kramer G., (2014). LCA of Dutch semiskimmed milk and semimature cheese. Based on: Comparative LCA of Dutch dairy products and plant-based alternatives. Available at: http://www.blonkconsultants.nl/wp-content/uploads/2016/06/FrieslandCampina-LCA-milk-cheese-C0.5.pdf

Busset G. Belaud J.P., Clarens F., Espi J., Sablayrolles C., 2012 Life Cycle Assessment of olive oil production in France. Engineering for Waste and biomass Valorization Conference 2012, At Porto, Portugal, Volume: 4

Caseificio Caramasche Soc. Coop. (2014). Carbon Footprint Study Report. Carbon Footprint Analysis: Parmigiano Reggiano DOP.

Cellura, M., Longo, S., Mistretta, M., 2012. Life Cycle Assessment (LCA) of protected crops: An Italian case study, Journal of Cleaner Production, 28, 56-62,

Djekic, I., Miocinovic, J., Tomasevic, I., Smigic, N., Tomic, N. (2014). Environmental life-cycle assessment of various dairy products. Journal of Cleaner Production, 68, pp. 64-72.

Doublet. G., Jungbluth N., Stucki M., Schori S. (2013) Sense project: Deliverable: D2.1. Life cycle assessment of Romanian beef and dairy products

Finnegan W., Goggins J., Clifford E., Zhan X.. (2017). Global warming potential associated with dairy products in the Republic of Ireland, Journal of Cleaner Production, 163, pp. 262-273

Flysjö A., Thrane M., Hermansen J. E. (2014). Method to assess the carbon footprint at product level in the dairy industry. International Dairy Journal, 34(1), pp. 86-92

González-García S., Hospido A., Moreira M.T., Feijoo G., Arroja L., (2013) Environmental Life Cycle Assessment of a Galician cheese: San Simon da Costa, Journal of Cleaner Production, 52, 2013, pp. 253-262.

ISO 14021:2016 Environmental labels and declarations -- Self-declared environmental claims (Type II environmental labelling) International Organisation for Standardisation, Geneva, Switzerland, 2016.

ISO 14024:1999. Environmental labels and declarations -- Type I environmental labelling -- Principles and

procedures International Organisation for Standardisation, Geneva, Switzerland, 1999.
ISO 14025:2006 Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures. International Organisation for Standardisation, Geneva, Switzerland, 2006.
ISO 14040:2006. Environmental Management – Life Cycle Assessment. Principles and Framework. International Organisation for Standardisation, Geneva, Switzerland, 2006.
ISO 14044:2006. Environmental Management – Life Cycle Assessment. Requirements and Guidelines. International Organisation for Standardisation, Geneva, Switzerland, 2006.
Kim, D., Thoma, G., Nutter, D., Milani, F., Ulrich, R., Norris, G. (2013) Life cycle assessment of cheese and whey production in the USA International Journal of Life Cycle Assessment, 18 (5), pp. 1019-1035.
Manfredi, M., Fantin, V., Vignali, G., Gavara, R., (2015). Environmental assessment of antimicrobial coatings for packaged fresh milk, Journal of Cleaner Production, 95, 291-300,
Manfredi, M., Vignali, G., (2014). LCA of a packaged tomato puree: a comparison of environmental impacts produced by different life cycle phases, Journal of Cleaner Production, 73, 275-284,
Manfredi, M., Vignali, G., (2015). Comparative Life Cycle Assessment of hot filling and aseptic packaging systems used for beverages. Journal of Food Engineering, 147, 39–48.
Milani FX1, Nutter D, Thoma G. (2011) Invited review: Environmental impacts of dairy processing and products: a review. Journal of Dairy Science, 94(9), pp. 4243-54.
Monini, S.p.A. (2012). Dichiarazione Ambientale di Prodotto (EPD®) di Olio Extra Vergine di Oliva “Delicato” available at: http://www.environdec.com/en/Detail/epd386,.
Salomone R, Ioppolo G (2012) Environmental impacts of olive oil production: a Life Cycle Assessment case study in the province of Messina (Sicily). Journal of cleaner production 28, pp. 88-100.
Salomone R, Ioppolo G ., Cappelletti G.M., Scimia E. 82010 Italian experiences in Life Cycle Assessment of olive oil: a survey and critical review. VII International conference on Life Cycle Assessment in the agri-food sector.
Tsarouhas P., Achillas Ch., Aidonis D., Folinas D., Maslis V., 2015. Life Cycle Assessment of olive oil production in Greece, Journal of Cleaner Production, Volume 93, pp. 75-83,
Van Middelaar, C.E., Berentsen P.B.M., Dolman M.A., de Boer I.J.M. (2011). Eco-efficiency in the production chain of Dutch semi-hard cheese. Livestock Science, 139 (1), pp. 91-99

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