VARIOUS ASPECTS OF MULTI-METHOD MODELLING AND ITS APPLICATIONS IN MODELLING LARGE INFRASTRUCTURE SYSTEMS LIKE AIRPORTS

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ABSTRACT

Large infrastructure systems like airports are complex, consisting of various subsystems that are interconnected dynamically to each other. Modelling only one subsystem, although the research question addresses only that subsystem, can lead to error propagations, as dynamic system effects are underestimated. Extending the system boundaries after identification of the dynamic effects can lead to trade-offs when the chosen modelling method gets to its limits. Combined systems require multi-method modelling where diverse subsystems are modelled with the respectively best fitting modelling method. These subsystems are connected via specifically defined interfaces to get a model that represents the large system. Multi-method modelling allows using all advantages of the different modelling methods by coupling them and give a more natural way of seeing the system. Different coupling methods found in literature are presented and basic concepts for modelling airports and its subsystems are proposed.

Keywords: multi-method modelling, agent-based modelling, system dynamics, airport planning

1. INTRODUCTION

The planning of big infrastructure developments is getting more challenging due to more complex structures and an increased number of construction standards. Large infrastructure systems can be decomposed into a a various number of **subsystems** that are somehow interconnected and also correspond on different levels with each other, what makes an analysis more difficult nowadays. Furthermore, there are different views on the system as well, that need to be addressed and satisfied: Stakeholders, planners, consumers, decision makers, etc. The diverse processes going on in these subsystems are connected in some ways that furthermore may not be apparent at first. In general this calls for modelling and simulation (see the real world in Figure 1 a), pictures by Bösch (2013)). These large systems, broken into pieces, consist of different subsystems with much more detail, each of them with its own dynamic effects.

1.1. Modelling Point of View

On the one hand the modeller can look at the **system as a whole**, decide which method suits best modelling the large system and answering the research questions. So in parts of the model of the large system the modeller has to make some trade-offs, where he can't go too much into detail, where it would have been necessary or where he goes too much into detail, where it was not necessary, see Figure 1b). So with the model, the system may not be represented as realistic as it could have been (*one model with one method for the whole system*). The method may not fit for the system as a whole.

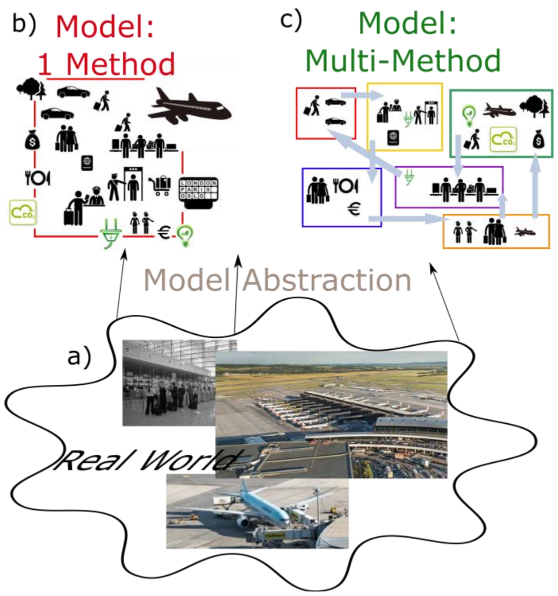

Figure 1: Modelling Large Systems

On the other side, when only modelling a **small part of a large system** with a specific modelling method and not taking into account effects from other subsystems the modeller again makes some trade-offs and propagated errors follow through the model (*one model* *and one method for a subsystem*). If the model boundaries only cover the subsystem, dynamic effects from outside that may be relevant are not considered. These effects then accumulate to serious dimensions and have a much stronger negative impact on the system state later on.

When different questions addressing for example the utilization of resources within one subsystem, or waiting times or even the planning process itself, arise, usually different modelling methods are used to model the specific subsystem trying to answer those questions. To get a more realistic model of the large system these different subsystems modelled with different methods can be coupled to get a **multi-method model** and to use all advantages of the methods for each of the subsystems, see Figure 1 c). Complex behaviour arises through the interconnection of different subsystems. Diverse studies found in literature call for use of multi-method modelling. Scholl (2001) even states, regarding Agent-based modelling (ABM) and System Dynamics (SD), that these "…*two techniques have a high potential for supporting and complementing each other. Joint ABM and SD research is proposed that may have the capacity for delivering results superior to those based on one technique only."*

The coupling mechanisms are diverse and dependent on the used methods. Difficulties and issues can arise. In this paper an overview of classifications on coupling methods found in literature will be given in 3. First, some definitions on terminologies will be provided in 2. In the next section we give some information on why we intend to test the proposed concepts in the area of airport planning.

1.2. Application Area: The Airport City

The concept of multi-method modelling is applied to airports and their decomposed subsystems, because airports or airport cities, as they are called due to the fact that they basically provide everything a real city provides as well, are **large complex socio-technical systems** where interactions between people and technology happens. Furthermore, according to Neufville (2013) aviation passenger and cargo traffic grew remarkably in the last years and will go on growing in the next years. Passenger traffic worldwide increased at an average of about 4 percent per year from 1990 to 2010. In 1990 more than 1000 million passengers were transported worldwide and in 2010 slightly more than 2500 millions, so it more than doubled in the last 20 years. According to the International Civil Aviation Organization ICAO (2015) it will increase in the next years as well, from 2012 4.9% growth rate (for passenger-kilometers performed) to 2015 with 6.3% growth rate. This is due to the fact that flying has become cheaper and safer and therefore planning and utilization of airports with respect to ecologic and economic factors is very important. Furthermore, according to Neuville (2013) there are three dominant trends in the airport and airline industry in the early 21st century:

- *Long term growth*: avg. 4% per year
- *Organizational change*: economic and political deregulation continues to spread worldwide (low-cost and integrated cargo airlines grow, privatization of airlines and airports)
- *Technical change*: in aircraft and air traffic control. The developments increase the efficiency and the capacity of airport facilities and processes. Airports need to adapt these new opportunities as they occur.

Airports, their structures and processes are complex, mostly not easy to understand and multiplex, which can be better analysed by modelling and simulation. In Figure 2 the different subsystems of a traditional airport are shown.

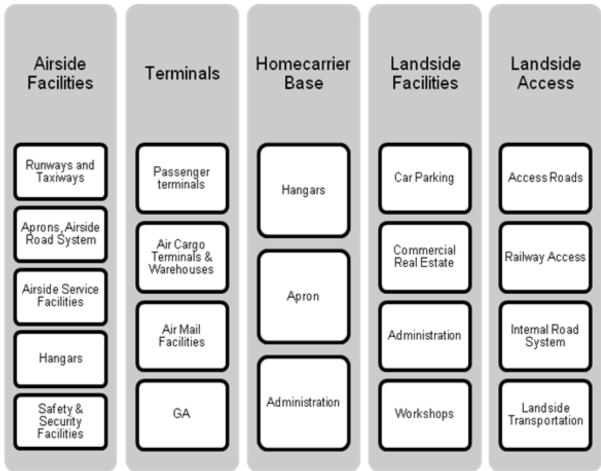

Figure 2: Subsystems of an Airport (Source: Company *AI-MS Aviation Infrastructure Management Systems*)

The main areas are:

- **Landside**: Passengers arriving by car, train, bus or taxi at the airport; Car parking; Administration;
- **Terminals and Retail**: Passengers going through check-in, passport control and security checks as well as the retail area; Cargo; Air mail;
- **Airside**: Airplanes departing and arriving; Ground handling processes; Airside facilities like runways; Air Traffic Control; Administration; Apron; Hangars; Control Centers;

Not only passengers are part of an airport system, but also personnel resources in different areas and material resources like planes, taxis, catering, cleaning, refuelling, etc. are part of the system, hence a socio-technical system. There are three main transportation goods: passengers, cargo and mail. Furthermore, there are operational aspects and strategic aspects in flight planning and aviation management that need to be addressed that also include meteorological forecasts (for flight planning and slot management), planning standards (for building or rebuilding airports), safety (which means operating without causing unacceptable harm) and security (which means freedom from unauthorised access, protection against attacks) questions, facilities programming and demand forecasts (ACRP 2010, Sterzenbach 1996, Maurer 2002). According to Neufville (2013) the planning design and management also has to include:

- *Dynamic strategic planning concepts* like the SWOT analysis: include *strengths* of existing site, *weaknesses* of facility, *opportunities* for the region and *threats* to the airport and region.
- *Market Dynamics:* Consumer behaviour, moving preferences, social relevance and also the competition of producers for market share.
- *Environmental impacts*: Aircraft noise, air quality, climate changes, water quality, wildlife and environmental legislation.

Planning, designing and understanding an airport system is complex. By optimizing buildings and especially large buildings in the early stages of planning savings of material and money can be achieved. If space is seen as an endless resource diverse ways of looking at a problem arise. If too many resources were planned the utilization of these resources can be seen as less efficient over time, which leads to unnecessary built space that needs expensive maintenance and inefficiency in the business. Some examples are: increased expenditure of energy or other resources, rising impervious surfaces. Inefficient process on built space can be made visible only by the dynamic utilization of space. With new strategies and intellectual approaches it will be possible to see space, its functionalities and its processes as ecologic relevant resources. The overall aim of modelling and simulation is to reduce the economic expenditures, as well as in increase the positive ecologic aspects. Also accessibility and transit time lengths are in the airport planning and other application areas very important components of the simulation. Usual planning errors like to small turning radius in toilets for wheel chair drives and inacceptable access paths for handicapped persons can be avoided. Different stakeholders need to be satisfied as well. For example projects in the area of airport planning on the development of air infrastructure address not only the planners and airports, but also the effects on industrial and touristic development of the whole region. These different views of planners, architects, airports, ministry, passengers and people who live in that region need to be included in a simulation and the interpretation of the results. This is an example why trade-offs in simulation of large infrastructure developments are not welcome and why a different approach is needed. In 4 a model concept for modelling some airport subsystems and the application of coupling methods as given in 3 will be proposed and discussed.

2. DEFINITIONS

Researching literature showed that there are multiple terminologies for modelling a large system with different modelling methods. Searching databases like *ScienceDirect*, *Scopus*, *Springer Link*, *IEEE Xplore* and *MathSciNet* by using terms and their combinations like "hybrid modelling" and "coupled models" in the first place, showed that other terminologies like "dynamic system modelling", "hyper modelling", "interconnected simulation", "interfaced simulation", "integrative modelling", "multi-method modelling" and many more are used for this kind of modelling as well. Swinerd and McNaught (2012), Sargent (1994) and Lättila (2010) refer to it as "hybrid models" or "hybrid modelling". They also proposed some methods of coupling Agent-based and System Dynamics models (see 3). Scholl (2001) referred to this kind of modelling as "multimethod and integrative approaches" and Schieritz (2003) referred to it as "integration", which makes it intuitively clearer what is meant than just saying "hybrid" modelling. Fishwick (2012) extends the meaning of "integrative modelling" or "multimodelling" and introduces a new term "hypermodel" to include interaction within models, among models and between human and models. On the other hand some of these terms, like "hybrid" are used for more specific or other interactions, like it is done in *Discrete-Event Modelling and Control of Hybrid Systems* by Nixdorf (2003): "hybrid" has a different definition in the context of modelling and simulation here and means that within one model *discrete and continuous* elements are modelled. Basically said, there are a lot of terms used for what intuitively is best understood as **multi-method modelling**.
Before we go on proposing what a multi-method model in our context is, we need to clear some definitions first: In the real world as seen in Figure 3, a **system** is a *set of interacting or interdependent components forming an integrated whole*.

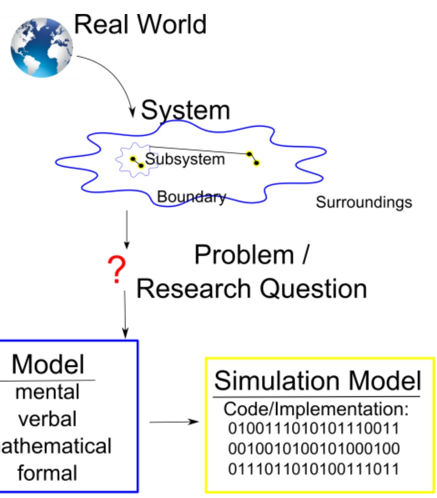

Figure 3: Building a Model out of the Real World

A **subsystem** is *a set of elements, which is a system itself, and a component of a larger system*. According to the system we look at a **problem** and a **research question** may occur. There are diverse standards how these questions have to be formulated, like in health economics and evidence based medicine the PICO standard (Gerber 2006). After having defined the research question a **model** can be derived. This can be mental, verbal or specific as a formal description. According to Preston White (2009) *"a model is an entity that is used to represent some other entity for some defined purpose. In general, models are simplified abstractions, which embrace only the scope and level of detail needed to satisfy specific study objectives".* A **simulation model** is the creation of a digital prototype of the model that is executable, also often referred to as a *computer model*.

If such a system is a large system it can be decomposed into **subsystems** where each of them can be modelled with another modelling method, forming a **submodel,** as seen in Figure 4.

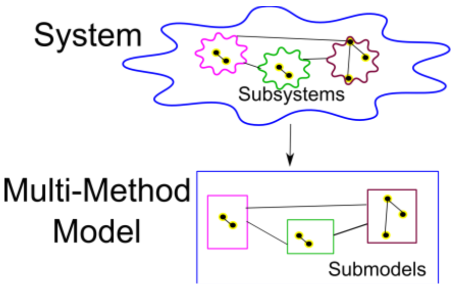

Figure 4: Decomposing the System into Subsystems and then creating Submodels with at least two different Modelling Methods.

The submodels for these parts of the system can be parallel or integrated and they can be on the same level or ordered hierarchically. A **multi-method model** is *a model that consists of at least two submodels, where at least two different modelling techniques are used.* These submodels *exchange information in some way. This process of information exchange* is called **coupling**.

2.1. Modelling Methods used here

Multi-method modelling with especially three modelling methods are researched and used as examples in the application of airport planning, because these methods are, according to literature, used most often in this area:

- Agent-based Modelling (ABM)
- System Dynamics (SD)
- Discrete Events (DES)

Agent-based modelling and Discrete Events are micro-based or individual-based modelling methodologies, best suited for modelling systems where the behaviour of (autonomous) individuals determines the system dynamics (Bonabeau 2002, Macal and North 2010). **Agent-based modelling** is a rather new modelling approach for which no consistent definition on what the modelling instances (agents) have to fulfil exists. **Discrete Events** models are similar, but the entity modelled here is not like an agent autonomous, but is passively led through the system instead. Furthermore, changes in the state of the system happen due to events at discrete points in time (Zeigler 2000). In between two consecutive events the state remains unchanged. This kind of modelling is mostly used in logistics and transportation. Another paradigm is set by **System Dynamics** modelling. Here the point of view is from another level, where only aggregated levels are looked at. It was developed in the 1950s by Jay W. Forrester, who applied it first in management systems (see Industrial Dynamics by Forrester (1997) or Urban Dynamics by Forrester (1973)). He then transferred this methodology to social systems. Nowadays diverse literature on *System Dynamics* and *Systems Thinking* exists (Sterman 2000). A SD model consists of stocks and flows, which basically is a set of differential equations. The dynamics of the system emerges from causal links of the modelled variables that often form feedback loops. Application areas are economics, health care, policy design.

These two modelling paradigms are different in view and offer different advantages. The one modelling method's advantage is the other ones disadvantage. So why not combine their advantages?

3. CLASSIFICATION OF MULTI-METHOD MODELS

In literature there are some classifications of multi-method models (they usually called it hybrid models) found. In this section a short overview on the (for the further work of this project) most promising definitions of classifications are summarized.

3.1. Original Classification Approach for Analytical and Simulation Models

Sargent (1994) suggested, based on his definition of a "hybrid model", which "*is a mathematical model which combines identifiably simulation and analytic models"*, four classes of hybrid models:

- Class I – *"A model whose behaviour over time is obtained by alternating between using independent simulation and analytic models."*
- Class II – *"A model in which a simulation model and an analytic model operate in parallel over time with interactions through their solution procedure."*
- Class III – *"A model in which a simulation model is used in a subordinate way for an analytic model of the total system."*
- Class IV – *"A model in which a simulation model us used as an overall model of the total system and it requires values from the solution procedure of an analytic model representing a portion of the system for some or all of its input parameters."*

This concept was used for actual *analytical models* (for parts of the system where time-dependent behaviour could be completely decomposed) and *simulation models.* This approach although done for analytical models (*a set of equations that can characterize a system or a problem entity*) and simulation models (in Sargent's (1994) context: *a dynamic or an operating model of a system or problem entity that "mimics" the operating behaviour of the system or problem entity and contains its functional relationships*) can be applied to simulation models with different paradigms as well, as Swinerd and McNaught (2012) showed for Agent-based and System Dynamics models in their work.
Sargent (1994) already found out that, what we call multi-method modelling, is needed to be researched, because these kinds of models are very useful in different application areas and have a lot of potential in modelling the world in a more realistic and effective way.

3.2. Adapted Classification for ABM and SD models
Swinerd and McNaught (2012) suggest for a system with AB and SD modules (here a module is seen as a submodel as we see it, representing a modelled part of the system) three classifications that are derived from Sargent's (1994) classifications (also see Figure 5):

- **Interfaced** (equivalent to Class I): two submodels with different modelling methods have some point of interaction or communication between elements; the submodel run *alternating* and *independently*;
- **Integrated** (equivalent to Class II): there are three methods suggested:
    - Agents with rich internal structure (also see Figure 6)
    - Stocked agents (also see Figure 7)
    - Parameters with emergent behaviour (also see Figure 8)
- **Sequential** (equivalent to Class III and IV): one submodel needs the output from the other submodel as input.

An **example for an interfaced model** as given in Swinerd and McNaught (2012) is: an AB submodel where a person (agent) walks along a street trying to reach his goal. Public traffic transportation is modelled by another submodel in DES. The agent can decide (within the AB submodel) if he wants to walk (stay in AB submodel) or if he wants to take the bus (DES submodel). He is either in one submodel or in the other, hence independent submodels that run alternating.
An **example for sequential model** according to Swinerd and McNaught (2012) is: *"[...] the Land Use Scenario Dynamics (LUSD) model which incorporates SD and CA modules. Within this design concept, the SD module firstly determines national and regional demand for land use based on factors such as land policy, demographics, market demand, the economy, and influence of technology. The CA module then provides a spatial representation of local land allocation to meet the aggregate demand defined by the SD module and considers local factors such as land suitability, land inheritance and the influence of neighbours. The output from the LUSD model is provided by the CA module and is in the form of a geographic map on which land change is plotted."*

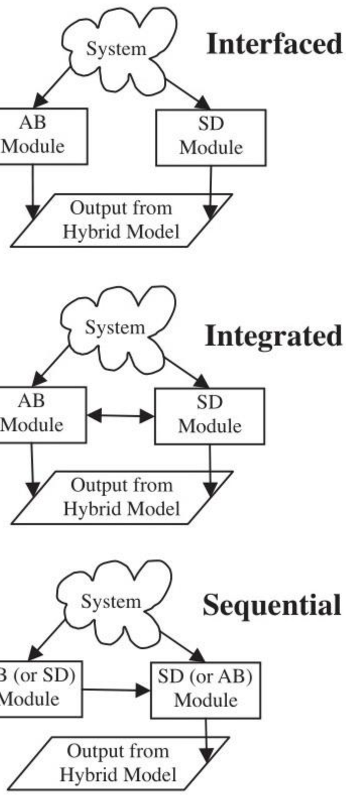

Figure 5: A Classification of Multi-Method Models according to Swinerd and McNaught (2012) for modelling Large Systems

Another example for a sequential multi-method model in airport planning would be an AB landside model that models passengers arriving at the airport by car, bus, train or taxi in order to enter a terminal module that is modelled with DES. First the necessary individual behaviour on the landside where passengers drive cars or arrive by some other vehicle is modelled. The individual behaviour is required for this module for modelling goal seeking strategies of agents that act autonomous and can decide where and when to go and how to react to their environment if something happens (street closed, parking houses closed, traffic jam, etc). In the terminal model (which will be explained more detailed in 4.2) questions addressing resource allocation or waiting times of passengers are answered. Simple server-queue structures call for DES modelling. First the passenger goes through landside and then through terminals. If this is purely sequential depends on what the modeller wants to include in the model. If the modeller also includes passengers that arrive at the airport by plane and proceed to the exit over the landside, this would be an integrated approach, because

interaction during the simulation time will be required as well.
An **example for an integrated model of *agents with rich internal structure*** is an AB model where each agent contains a SD model, as seen in Figure 6 (by Swinerd and McNaught (2012)). One can think of the SD model of an agent as the agent's "brain" that "tells" him what to do in a dynamic way. Here influences from both sides can be considered: AB submodel passes information to the SD submodel and vice versa.

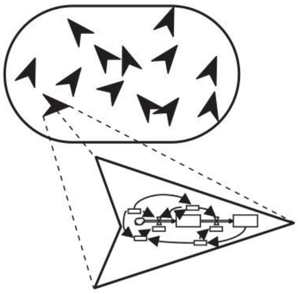

Figure 6: Integrated Multi-Method Model: Agents with Rich Internal Structure

An **example for an integrated model with *stocked agents*** is "*a level within an SD model that is used to bound an aggregate measure of an AB module"* (see Figure 7, Swinerd and McNaught (2012)). This could be an SD submodel that calculates production costs on car sales and the influence of fuel price on consumer choice of vehicle technology where consumers are modelled in the AB submodel. Here only influences from SD to AB are modelled, but not the other way round.

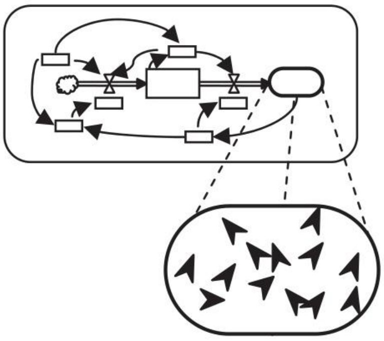

Figure 7: Integrated Multi-Method Model: Stocked Agents

An **example of an integrated model with *parameters with emergent behaviour,*** as seen in Figure 8, is an AB submodel where demographic development is modelled with agents together with their individual attributes (age, sex, maybe socio-economic factors). Out of these attributes the value of a parameter for a coupled SD submodel is calculated. According to Swinerd and McNaught (2012) this could be the participation of a population to the pension fund of a country that is modelled with SD.

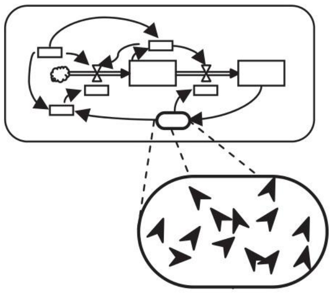

Figure 8: Integrated Multi-Method Model: Parameters with Emergent Behaviour

Basically, there is a fine line between the classes of multi-method models and the modeller has to decide what fits best. It is also dependent on where the system boundaries lie (see comment after example of sequential model above). This classification approach is very useful as a starting point in researching multi-method modelling, since it is also applicable not only for SD and ABM modelling but also for other modelling methods. In the next chapter some examples and concepts of multi-method models in the area of airport planning will be given.

4. APPLICATIONS IN AIRPORT PLANNING

There are many subsystems of an airport, as seen in Figure 2, and in the next three sections a concept for three subsystems and their coupling mechanisms of the multi-method model will be proposed. Some of the subsystems are currently being developed in AnyLogic 7 and others will be implemented during further research of this project. The general advantage of this modular set-up that is included in this multi-method modelling technique. Is that it can be extended for other subsystems in the future to include more influencing parts of the airport city system as well. First some notes on available data and passengers will be given and then existing concepts and existing tools will be explained shortly.

4.1. Some Notes

For most simulations a so-called *Design Peak Day* from the Vienna International Airport, where data for incoming and outgoing flights, their destination respectively origin together with planned and actual arriving respectively departing time and actual time is available. Furthermore, it holds information on how many passengers were transported. According to this Design Peak Day, which represents an optimal day for this airport, number and time of arrival or departure of passengers can be retrieved for the simulation.
There is a main differentiation in passengers: *Tourist Passengers* and *Business Passengers*. Data on who is tourist and who is business can only be estimated, but this is relevant because these different types of passengers have different behaviours in for example arrival time at the airport before departure, amount of luggage carried with them, shopping behaviour in the retail area or travel time.

4.2. Terminal

The terminal area is after the landside area the second area where departing passengers go to. The processes going on include check-in, security controls, passport controls and proceed to gate through retail area (Schulz 2010). In Figure 9 a diagram of the diverse processes according to Schulz (2010), only translated to English can be seen.

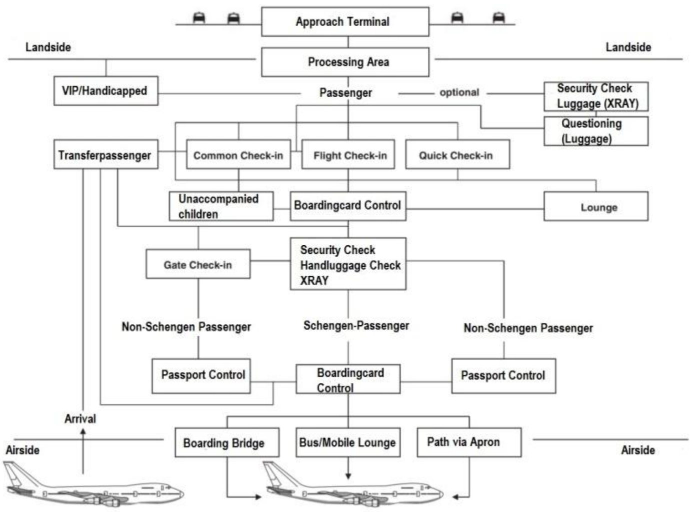

Figure 9: Processes in the Terminal (Schulz 2010)

These are dependent on specific features of the passenger, like if he is *business* or *tourist* (only hand luggage or not), or what his destination is (if within Schengen, then the passenger can proceed without passport control) or if he is handicapped or not. This submodel also includes *transfer* passengers, meaning passengers arriving at the airport by plane, going through passport control if necessary and proceeding to gate after going through retail area. This circumstance shows on the one hand, that this submodel gets input from the landside as well as from the airside and if some delays or other effects happen in the parts of the airport not represented in the terminal submodel it has an effect on the terminal submodel.

The research question in this model is if resources like personnel and number of open counters is enough at each time to maintain the quality standards measured in waiting time of passengers. This being a simple server-queue question is modelled best using **Discrete Events** with counters and personnel being resources and passengers being entities. Like mentioned in 4.1 there is a differentiation in passengers: business and tourist.

A first version of a DES model has already been implemented, as seen in Figure 10. This model includes the basic servers in such a process (check-in, security, passport control and transfer) and distinguishes between tourist and business passengers. In AnyLogic simple blocks for creating (sources), processing (server), and queuing (queue) entities are used. Resources are created via a (scheduled) resource pool. Here, sources and sinks (Exit) build the interface to an adjacent submodel where entites are led through the system.

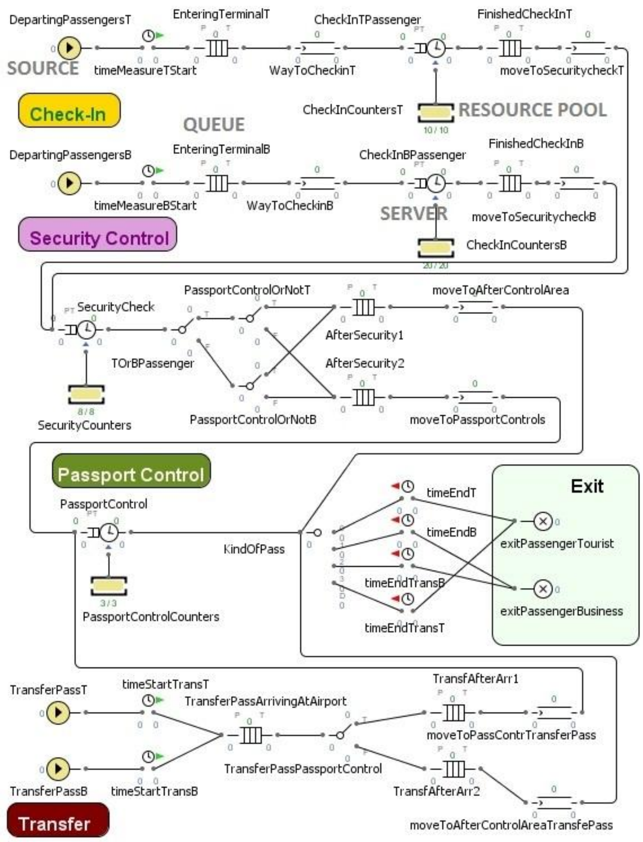

Figure 10: Example of an Implementation in AnyLogic of the Terminal Model.

Now a simple agent based model modelling the landside can be coupled by this rule: every time an agent (passenger) exits the landside model via a port, an entity (it is possible to pass other information as well) in the DES model is generated. On the other side the exit can be seen as an interface as well. Passengers proceed to the gate through the retail area. Every time an entity enters the sink in the DES model an agent will be created in the ABM model of the retail area (which will be explained in the next section.

4.3. Retail Area of an Airport

The retail area is economically seen a very important part of the airport since a large part of the profit is gained by the retail area. The retail area is a shopping area after having passed the controls in the terminal where passengers go through when they proceed to the gate to depart. One main research question in this area is to maximize profit by guaranteeing a specific level of quality standard for passengers like a short way to the gate or attractive sales. What we propose here is a multi-method model itself: **an AB submodel that includes spatial information** (map of the shops) where passengers walk through the retail area as agents. The environment is the retail area with the shops. **Each agent representing passengers consists,** next to some individual parameters, **of an SD submodel** that models the *need to eat* and the *need to buy* other things. In this case the retail submodel is itself an **integrated form of agents with rich internal structure** as seen in Figure 6. The agent still follows some rules like:

- proceed to gate in time
- if hungry and still time to departure, then look for eating store and eat
- in dependence of attractiveness of store and in dependence of estimated income buy something if there is still time to departure and the need to buy something exceeds a specific threshold

These rules always take into account the by the SD model calculated *need* to buy something. This means there is communication from the SD module to the agent based module (tell him where to go). In return the need is dynamically calculated by the SD module by using individual information from the agent (age, gender, time until departure), but also using information from the environment of the AB module, like the attractiveness of the store that has some "basic attractiveness" and furthermore is calculated by the number of people inside (if no people are inside it may be something wrong with it, if too much people are inside it is overcrowded).

A first version of this submodel is in development (work in progress by M. Obermair and B. Glock), as seen in the 3D version of the animation in Figure 11 implemented in AnyLogic 7. A network is applied to a groundfloor and passenger agents interact on this plan with the shops trying to satisfy their goals.

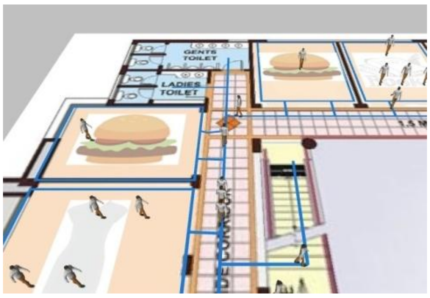

Figure 11: Retail Area modelled with Agents (Screenshot by M. Obermair).

4.4. Airside

The airside of the airport is the part where diverse processes take place that deal with outgoing and incoming planes, like it is shown in Figure 12.

The so called ground handling processes include all processes around the plane. After touchdown (landing of the plane), the taxi arrives to get the passengers. After that the unloading, deboarding and water refillment starts. There are some limitations like cleaning and catering have to start after deboarding or fuelling after unloading luggage that need to be considered as well. In this submodel the spatial context plays an important role since travelling times contribute to quality measurements for passengers and the calculation of optimizations regarding the ground handling process itself.

The amount of flights is increasing and space on the airside where passengers can board (directly through the gate vie boarding bridges or on the apron) is limited.

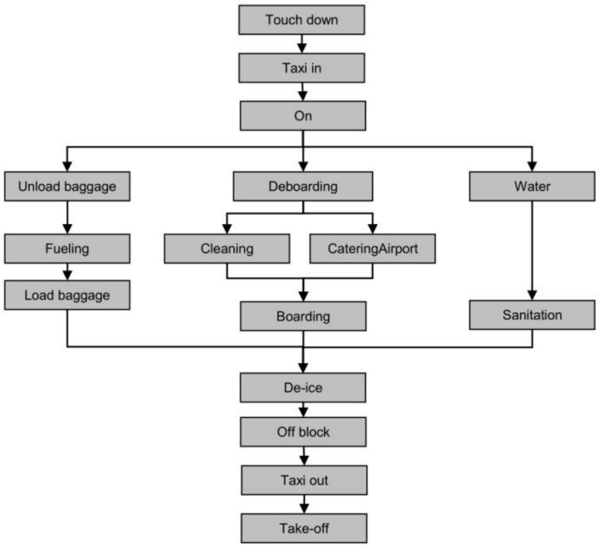

Figure 12: Ground Handling Process (Norin 2012)

Therefore, in this case an **AB submodel** is suggested with a given **network** on which the agents can operate, as seen in Figure 13.

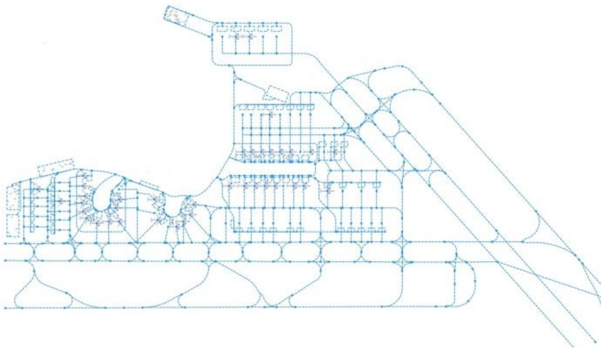

Figure 13: Example of an airside network of the Vienna International Airport.

Different types of agents interact with each other on an environment (network):

- Planes
- Mobile stairs
- Catering vehicle
- Belt loader
- Baggage cart
- Container/pallet dolly
- Container loader
- Tractor
- Lavatory service vehicle
- Refuelling vehicle

- Dispenser vehicle
- Ground power unit
- Air conditioning unit
- Pushback tug

They have one overall goal to get the plane as soon as possible up in the air again.

4.5. Coupling of the modules

Summarizing the proposed submodels as seen in Figure 14 there is a terminal submodel in DES that interacts with the retail submodel in ABM, which is itself a multi-method model due to the "brain" of each agent being a SD submodel. The retail submodel is connected to the airside submodel. If we model only one way of passengers, the departing passengers this would be a sequential approach. If we include a landside submodel and furthermore include passengers arriving at the airport by plane on the airside that then proceed to the landside we would call it an integrated model, because these submodels would have to exchange information (eg. the agent or entity being passed on) as well.

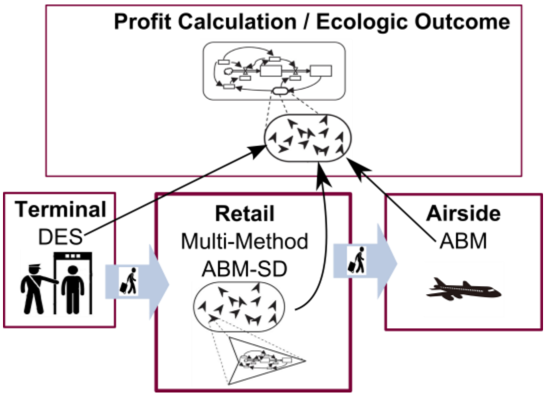

Figure 14: Proposed Multi-Method Model of Parts of the Airport.

Another further possibility as seen in Figure 14 is to build a hierarchically higher SD model that uses input from the "lower" submodels to calculate ecologic outcomes or profit calculations as well.

5. CONCLUSION AND OUTLOOK

Using multi-method models is getting more important every day, since systems and structures get more complex and larger. Errors by using only one method for a large system can accumulate over time and make decision making much more difficult. By using different (best fitting) modelling methods for different subsystems and utilizing all their advantages on the one hand a *more realistic presentation* of the multi-method model can be created (what makes communication to decision makers easier) and on the other hand *accumulating errors can be eliminated* to some extent. Furthermore, *calculation times of the simulation models can be reduced*: If a modeller would have used for example an AB model to model the whole system, but with multi-method modelling now uses only a small AB module where necessary and in other parts of the model a DES model or a SD model where not so much detail or individual behaviour is needed, the calculation time of simulating the large system can be reduced significantly. In future work of this project the proposed submodels will be finished implementing to get a glance on what may be possible in modelling large infrastructure systems and how methodologies can be refined, researched and made better.

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REFERENCES

ACRP Airport Cooperative Research Program, 2010. ACRP Report 25, Airport Passenger Terminal Planning and Design – Volume 1: Guidebook. Washington, D.C.: Transportational Research Board.

Bonabeau E., 2002. Agent-based modelling: Methods and techniques for simulating human systems. Arthur M. Sackler Colloquium of the National Acandemy of Sciences "Adaptive Agents, Intelligence, and Emergent Human Organization: Capturing Complexity through Agent-Based Modeling". October 4-6, Irvine, CA.

Bösch R., 2013. VIE Metamorphosis. The Extension and Transformation of Vienna Airport. Wien: Springer.

Fishwick P.A., 2012. Hypermodelling: an integrated approach to dynamic system modelling. Journal of Simulation 6:2-8.

Forrester J.W., 1973. World Dynamics. Cambridge, Mass.: Wright-Allen Press.

Forrester J.W., 1997. Industrial Dynamics. Portland: Productivity Press.

Gerber A., 2006. Gesundheitsökonomie und Pädiatrie. Schattauer.

ICAO International Civil Aviation Organization. Predicts, 2015. Available from: http://www.icao.int/Newsroom/Pages/ICAO-predicts-continued-traffic-growth-through-2015.aspx [Accessed: 14th May 2015]

Lättila L., Hilletofth P., Lin B., 2010. Hybrid Simulation Models – When, Why, How?. Elsevier Expert Systems with Applications 37:7969-7975.

Macal C.M., North M.J., 2010. Tutorial on agent-based modelling and simulation. Journal of Simulation 4:151-162.

Maurer P., 2002. Luftverkehrsmanagement - Basiswissen. Oldenbourg: Oldenbourg Wissenschaftsverlag.

Neufville R. De., Odoni A., 2013. Airport Systems – Planning, Design and Management. 2nd Edition. United States: The McGraw-Hill Education LLC.

Nixdorf, B., 2002. Discrete Event Modelling and Control of Hybrid Systems. Düsseldorf: VDI-Verl.

Norin A., Granberg T.A., Yuan D., Värbrand P., 2012. Airpot logistics – A Case Study of the turn-around process. Journal of Air Transport Management 20:31-34.

Preston White K., Ingalls, R., 2009. Introduction to Simulation. In: Proceedings of the 2009 Winter Simulation Conference, pp.12-23.

Sargent R.G., 1994. A Historical View of Hybrid Simulation/Analytic Models. In: Proceedings of the 1994 Winter Simulation Conference, pp. 383-386. December 11-14, Orlando, Florida.

Schieritz N., Milling P.M., 2003. Modeling the Forest or Modeling the Trees – A Comparison of System Dynamics and Agent-Based Simulation. In: Proceedings of the 21st International Conference of the System Dynamics Society. July 6-9, Waikoloa, USA.

Scholl H.J., 2001. Agent-based and System Dynamics Modelling: A Call for Cross Study and Joint Research. In: Proceedings of the 34th Hawaii International Conference on System Sciences. January 3-6, Maui, USA.

Schulz A., Baumann S., Wiedenmann S., 2010. Flughafen Management. München: Oldenburg Verlag.

Sterman J.D., 2000. Business Dynamics: Systems Thinking and Modelling for a Complex World. Boston, Mass: Irwin McGraw-Hill.

Sterzenbach R., 1996. Luftverkehr – Betriebswirtschaftliches Lehr- und Handbuch. München: Oldenburg Verlag München Wien.

Swinerd C., McNaught K.R., 2012. Design Classes for Hybrid Simulations Involving Agent-based and System Dynamics Models. Elsevier Simulation Modelling Practice and Theory 25:118-133.

Zeigler B., Praehofer H., Kim T.G., 2000. Theory of Modelling and Simulation – Integrating Discrete Event and Continuous Complex Dynamic Systems. 2nd Edition. London:Academic Press.

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