Single wagonload production schemes improvements using GüterSim (agent-based simulation tool)

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Abstract

Single Wagonload (SWL) is still a major component of the Swiss freight transportation system. To hold the market share of the SWL system a reduction of production costs and an increasing quality is needed. To evaluate alternative production schemes and the effects of technological innovations a simulation tool is necessary. Since there are no suitable tools available which cover all needs for a SWL simulation, the IVT developed a new agent-based tool called GüterSim on the basis of the existing software MATSim. GüterSim models the routing of the freight wagons, as agents, according to the routes in the real SWL network and the production schemes. It is a scalable model with two network levels and an integrated approach.

This paper presents the following achievements: Modeling existing timetables and routing of freight trains; opportunity for improvements of train routings and schedules to optimize the existing productions scheme; integrating the capacity restrictions of the infrastructure to check the realizability of the improvements; automatic timetable generation on the existing network; and automatic generation of new production systems. A case study is presented to prove model’s application.

The work is based on real data from the SWL Swiss network which includes infrastructure data, schedules, rolling stock and locomotive data. Therefore the conclusions are based on real freight demand within the Swiss freight network. GüterSim is proved as a tool to improve SWL production schemes and scalable to other freight networks with fixed schedules.

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1. Introduction and motivation

Single wagonload (SWL) transport is still considered as a major component in numerous European states transport systems and in the logistics of different economic sectors such as steel, chemical industry and automotive. However changing framework conditions and increasingly demanding market requirements have led to dramatic market losses and even to complete shutdown of SWL business in some countries. As this business segment has been evaluated as important for specific transports in a European co-modal transport system also in the future, significant improvements are needed. Compared to other European Countries, the SWL in Switzerland is in a good state. About 50 percent of all domestic, import and export rail transports are handled by SWL. However, even in Switzerland, the SWL must face the pending challenges. On the one hand, a continuous optimization of the production network and a reduction of the number of shunting yards takes place. On the other hand SWL in Switzerland has to deal with rapidly growing passenger traffic, which is prioritized in the network access. Thus, the number of available train paths for SWL is reduced. To remain competitive against road transport, SWL has to cover even under these boundary conditions all national relations in Switzerland in an overnight service. To meet this requirement the production system must be continuously improved. To increase the competitiveness of SWL compared to road transport an optimization of the production schemes is necessary. The main goal is increasing the quality of SWL and the reduction of production costs. Thus, the sector has identified four approaches:

- Increase of the utilization of trains – to reduce the number of trains, because currently trains are used at 60% of capacity and therefore cost per wagon transported has room for improvement.
- Stabilization of the train occupancy to achieve a more sustainable service.
- Reduction of the deviation of wagons, due to current complicated wagon routing.
- Enhancement of the supplied services by shorter transport times because they are currently longer than road freight transport times.

In section 2, the state of the art of SWL systems and SWL optimization approaches are presented. In section 3, GüterSim model is explained. It is a SWL agent-based model that includes infrastructure, production and shunting processes. In section 4, case study for improvements on the Swiss SWL network is presented. Finally, in section 5, the conclusions summarize the work presented and evaluate the potentiality of implementation of this method as a short and mid-term solution until more technological means are implemented in daily based SWL schedule planning.

2. State of the art

The state of the art describes the two fields that influence this research, which are the current practices on the SWL network in Switzerland and the most recent research developments in SWL modelling.

2.1. Best practices in Switzerland

Nowadays most of the European railways use a modified hub-and-spoke-system for their SWL production schemes (Bruckmann 2007). In Switzerland the SWL production scheme consists of a three stage collection and distribution system. The first stage consists of the satellites including the sidings where the wagons have their origin and destination. The second stage consists of the regional production points where the trains to the shunting yards are formed and as a third stage the shunting yards.

2.2. Current modelling approaches

SWL is a complex system where several elements play an important role, e.g., freight planning, train operations, shunting processes and network structure. Literature shows different methods to optimize separately the elements of SWL systems, but no integrated approach until now is known. For instance, regarding freight planning, Marinov et al. (2012) talk about SWL services and how policy and practice can benefit from scientific methods and information
technologies. It concludes that there is a need to update freight planning models in order to better support decisions for effective rail freight services and address current rail freight needs. This paper states that specific software platforms for the simulation of railway systems have been developed.

On the other hand, for the modelling of the train operation on the railway lines many commercial systems like OpenTrack, RailSys etc. are available. In these models the entire rail operation is simulated on a very detailed level. As input data the complete infrastructure (including all tracks, all signals, all switches) and a detailed schedule is needed. These systems seem to be too detailed for a long-term optimization of SWL production schemes. On the basis of SIMUL 8 Marinov and Viegas (2011) developed an event-based mesoscopic simulation system for a single rail freight line.

Moreover, for the optimization of shunting processes several models already have been used. So the University of Zilina and Simcon developed a commercial simulation program for shunting yards, which was already applied in Switzerland (Zat’ko and Leber 2006). These tools simulate the shunting process in detail but do not generate automatic solutions for the problems in the yard. For an optimization of the sorting program of a shunting an overview is given in Boysen et al. (2012).

Furthermore, for the optimization of network structure Bruckmann (2007) used a macroscopic tool from Railion. For a part of the Swiss SWL network Ceselli et al. (2008) developed an optimization approach. Also some commercial models for a manual optimization of SWL networks are available. So the Austrian Railways and IVE Hannover developed a Network Evaluation Model (NEMO), Sewcyk and Kettner (2001), to optimize the freight network in Austria. Another commercial tool is Multirail provided by Oliver Wyman (2013) which provides a wide range of manual optimization possibilities.

Finally, agent-based approaches to freight simulation were already considered from Kavicka, et al. (2007) on an ABASim basis. Also the MATSim approach is considered to be used for freight transportation modeling. But till now these are only conceptual papers. In this paper a concept for modeling the behavior of shippers to increase the quality of models for demand and modal choice is described (Schroeder et al., 2012). A MATSim approach for a network optimization is not considered. Even a real-world application of MATSim for freight purposes is not known until now.

To evaluate alternative production schemes and the effects of technological innovations a simulation tool, which models the production schemes as well as the infrastructure capacities is needed. Since the existing tools either model the infrastructure or the shunting processes or the network structure an integrating approach on a mesoscopic level is needed. With such a simulation tool the interdependencies between several optimizations can be considered, so that additional benefit may apply.

3. GüterSim, the SWL simulation

GüterSim is built as an agent-based simulation on MATSim basis. It follows an activity based approach for traffic simulation as described in Balmer et al. (2008). The general approach is iterative: starting from an initial condition, the system optimizes the behavior of the agents. The experiences of the agents in former simulations are considered in the following ones. For generating a MATSim model first a population of agents with their activities is needed. For each agent, based on these activities, a schedule is defined. The schedule includes e.g. the number and type of activities, the sequence, the starting and ending time of the activities, their mode choice and their route choice and the grouping of agents travelling together. Additional already existing traffic flow simulations are available for MATSim including public transport (Reiser 2010). In public transport the main parameters are the buses (or trams) which are driving on fixed lines with a schedule and a set of stops having a maximum capacity. If the demand is higher than the capacity the passengers the last passengers entering a bus are left on the bus-stop (first-in first-out).
For modeling the SWL network in GüterSim the MATSim approach has to be adapted to the needs of the SWL (Bruckmann et al., 2014). The aim of the tool is to model the routing of the freight wagons according to the routes in the real SWL network. Therefore a specific modeling of the network, the schedules and the agents is required. As a first step the existing timetable has been modeled. But the modeling approach is as open as possible to allow also further steps of an automatic network and timetable generation. The wagons are simulated as the agents, with O-D information as activities. The locomotives are simulated as the buses or trams of the MATSim public transport model. Each part of the SWL system has to be modeled in MATSim: the demand, the schedule of the trains including the infrastructure network and the shunting processes. There are two network layers: infrastructure and operations.

The infrastructure layer models capacities and available train routes. The capacities are restricted by the number of available train paths for freight trains. In Switzerland there is an integral fixed-interval timetable. So, also for the freight trains a fixed number of train paths is reserved in a standard hour. In the peak hour of the passenger transport this number of train paths is reduced due to extra trains. For the generation of new schedules and for an automatic train routing on the network these restrictions have to be considered. The physical infrastructure is modelled as a graph containing nodes and edges. The nodes represent stations and junctions, and the edges are the lines between the nodes. The edges contain information about their length, the maximum speed of the trains, a maximum capacity, the maximum train length and train weight. To model the constraints on junctions, the edges are directed. So the extra time needed for a change in the direction of travel can be modelled by an additional edge.

The production layer models the assignment of the access points (sidings) to regional shunting points and shunting yards. It also includes the train-schedules and the commercial stops of the trains at the stations, where a pick-up and set-down of wagons is possible. The first element of the production scheme model is the demand. For the model, the demand data for the Swiss SWL network for one day is used. Each wagon transported during this day is considered as one single agent with a origin and destination. The starting time at the origin is set fixed to 2 p.m. as no further detailed data is available. In latter versions of the model the demand can be modelled with a specific origin time for each wagon in each siding. Each wagon has a length and a gross weight to model capacity constraints on the trains.

The second part is the schedule of the trains. Each train (or group of trains with the same origin, destination and commercial stops) is modelled as one public transport line. Each line has one dedicated type of vehicle (locomotive) with a specific maximum speed, a maximum train length and maximum train weight. So, on the commercial stops wagons can board until the maximum train length or the maximum train weight is reached. If the number of wagons
on a stop exceeds the capacity of a train, the wagons will be left on the station. To calculate the network-load of the infrastructure network, in a next step the trains of the production network are routed on the optimal path. In the current model only the travel times are used as routing criteria. For the calculation of travel times the model considers the length of the edge, the average speed of the trains and the time for changing the locomotive, when the train changes the direction of travel.

The third part is the modelling of the shunting. To simulate the shunting time, a wagon arriving at a station is stored in a shunting loop for a specific time. The maximum shunting capacity (wagons per hour) is modelled by a capacity restraint on this loop. The shunting time and capacity depends on the type of station. So shunting with locomotives has a shorter shunting time and a small capacity. Shunting yards with a hump have a large capacity but also a longer shunting time.

For the routing of the wagons the existing iterative MATSim routing algorithm is used. In the first iteration some of the wagons do not reach their destination due to the capacity constraints on the networks. Several optimization loops are done. In each loop 20 percent of the wagons are rerouted on a new optimal route. This optimization routine continues until each wagon has found a possible route, or there is a stable solution with wagons which do not find a suitable route.

The results of the simulation apply in a events file, which contains all events during the simulation. In general, data analysis can be done on the basis of this events file using Java or standard statistic software. To extract important characteristics in a short time the SENOZON-tool Via is used. This tool also allows a time dynamic visualization.

Fig. 2. (a) model of the infrastructure network (example with split up of two lines); (b) actual Swiss SWL production network in MATSim.

4. Case study: Modification of train routings and schedules to improve the existing production scheme in the Swiss SWL network

4.1. Concept

Operators need short and mid-term improvements on the production level to make the network more efficient but the sector usually struggles with budget restrictions. Furthermore, modifications are usually implemented on the network without certainty of success. Therefore, this case study presents an approach for local improvements on the production network that overcomes the certainty problem.
To improve the existing production scheme in the Swiss SWL network, a modification of train routings and schedules has been executed using GüterSim. The aim is to find scenarios that can improve network’s productivity and could be implemented in short and midterm by operators just using current scheduling technics. Two different strategies for improvement have been modelled.

The first strategy is to bundle trains that share part of their commercial route: respecting the existing operational network (commercial routes, shunting yards and regional shunting points), the traffic of a specific commercial route is reorganized by bundling existing trains with same shunting yard origin (or destination) which share part of their commercial route.

The second strategy is to bundle trains that serve the same region: respecting the existing operational network (commercial routes, shunting yards and regional shunting points), the traffic from a specific shunting yard towards the same region are bundled and later split to serve the last commercial stops.

A new type of vehicle (locomotive) with same maximum speed but half maximum train length has been introduced in the model to run some of these new paths, so when trains are bundled they do not overpass the maximum length allowed. Maximum train length in the model is 750m, the maximum train length in most of Swiss rail sections. Nevertheless, SWL trains length in Swiss network usually do not exceed 450m (60% of their capacity).

Six regions and/or commercial routes have been selected from the current Swiss SWL network to be modified using the aforementioned strategies when simulating on GüterSim. The goal is to evaluate the impact these local modifications have on the overall performance of the network. To simulate each modification the following steps have been followed:

- Identification of all trains serving the selected shunting yard and regional shunting points in any direction.
- Substitution of these trains for a new service: 3 trains per day in each direction, none intermediate stops between the shunting yard and the regional shunting points, coupling and decoupling activities allowed if needed.
- Creation of a new schedule that includes these changes and keeps the previous services in the rest of the network.

4.2. Data preparation

In order to model the SWL network data provided by SBB Infrastructure was used. The data provided include information about stations, wagons, locomotives, and schedules. Part of this data was implemented by Senozon to
the GüterSim model to create the layer that represents the infrastructure of the network. The data contained the name and code of the stations, and their coordinates. This information was used to build up the nodes of the network, and the tracks that connect those stations were approximated by connecting the nodes in straight lines. The density of nodes on the network is big enough to offer a realistic approximation of the infrastructure network.

The schedules used for the simulations are a result of a combination of data provided by SBB Infrastructure and the SBB graphic timetables. It was needed to use the second data set because the first data set was incomplete. When the first test of the model was executed only using SBB Infrastructure schedule, several stations on the model were not served by SWL trains. Therefore it was decided to complement it with the SBB graphic timetables (available in pdf format on the website).

4.3. Simulation and results

The Swiss SWL network is simulated in GüterSim using the aforementioned infrastructure and schedule data. GüterSim simulates 72 hours of network performance out of one day demand data to model wagons O-D. The system contains 4100 wagons. To evaluate the modifications, five key performance indicators (KPIs) are selected: train-kilometers; train-hours; wagon-kilometers; wagon-hours, and tonne-kilometers.

After the simulation wagons are counted as “Transported wagons” or “Stuck wagons”. Transported wagons are the ones that are loaded on train during the simulation although they might or might not reached their final destination. Stuck wagons are the ones that did not reach their final destination during the simulation. They might or might not be loaded into a train during the simulation. Therefore, total wagons = stuck wagons $\cup$ transported wagons $\setminus$ (stuck wagons $\cap$ transported wagons).

<table>
<thead>
<tr>
<th>Stuck wagons</th>
<th>Transported wagons</th>
<th>Train-kilometers</th>
<th>Train-hours</th>
<th>Wagon-kilometers</th>
<th>Wagon-hours</th>
<th>Tonne-kilometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.59%</td>
<td>97.41%</td>
<td>102896</td>
<td>2463</td>
<td>401519</td>
<td>68378</td>
<td>15,546,472</td>
</tr>
</tbody>
</table>

There are two reasons to the wagons not reaching the final destination. Either the entire shipment requires longer simulation time given that the simulation represents 72 hours schedule but some wagons might need to wait longer due to transshipments; or their origin or destination stations are not served due to the fact that data is not complete and in some cases schedule and infrastructure data do not match.
The results of the simulation for each Local Modification (LM) are presented in Table 2. Results are presented as percentages. They indicated the variation of KPIs compared to KPIs of the current Swiss SWL network production schemes given in table 1 (original scenario). The negative values indicate that the KPI has been reduced as compared to the original scenario, implying an improvement in efficiency of the network and use of resources.

<table>
<thead>
<tr>
<th>KPI</th>
<th>LM 1</th>
<th>LM 2</th>
<th>LM 3</th>
<th>LM 4</th>
<th>LM 5</th>
<th>LM 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stuck wagons</td>
<td>-5.40%</td>
<td>4.32%</td>
<td>1.73%</td>
<td>2.70%</td>
<td>-4.06%</td>
<td>1.19%</td>
</tr>
<tr>
<td>Transported wagons</td>
<td>0.02%</td>
<td>0.03%</td>
<td>-0.15%</td>
<td>0.03%</td>
<td>0.55%</td>
<td>0.03%</td>
</tr>
<tr>
<td>Train-kilometers</td>
<td>0.17%</td>
<td>-3.25%</td>
<td>-0.13%</td>
<td>1.88%</td>
<td>-5.95%</td>
<td>0.18%</td>
</tr>
<tr>
<td>Train-hours</td>
<td>-0.13%</td>
<td>-1.08%</td>
<td>0.61%</td>
<td>1.68%</td>
<td>-7.22%</td>
<td>0.08%</td>
</tr>
<tr>
<td>Wagon-kilometers</td>
<td>-3.95%</td>
<td>-11.42%</td>
<td>-4.88%</td>
<td>-4.27%</td>
<td>-0.91%</td>
<td>1.44%</td>
</tr>
<tr>
<td>Wagon-hours</td>
<td>-0.55%</td>
<td>0.00%</td>
<td>-2.26%</td>
<td>-0.12%</td>
<td>2.23%</td>
<td>-2.42%</td>
</tr>
<tr>
<td>Tonne-kilometers</td>
<td>-4.33%</td>
<td>-12.08%</td>
<td>-5.45%</td>
<td>-5.40%</td>
<td>-1.57%</td>
<td>0.60%</td>
</tr>
</tbody>
</table>

Table 3. KPI values on wagon-kilometers and wagon-hours divided by wagons transported.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Original</th>
<th>LM 1</th>
<th>LM 2</th>
<th>LM 3</th>
<th>LM 4</th>
<th>LM 5</th>
<th>LM 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wagon-kilometers</td>
<td>100.53</td>
<td>96.87</td>
<td>89.03</td>
<td>95.77</td>
<td>96.21</td>
<td>101.76</td>
<td>101.96</td>
</tr>
<tr>
<td>Wagon-hours</td>
<td>17.12</td>
<td>17.08</td>
<td>17.12</td>
<td>16.76</td>
<td>17.10</td>
<td>17.88</td>
<td>16.70</td>
</tr>
</tbody>
</table>

Table 4. KPI values on wagon-kilometers and wagon-hours divided by total wagons.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Original</th>
<th>LM 1</th>
<th>LM 2</th>
<th>LM 3</th>
<th>LM 4</th>
<th>LM 5</th>
<th>LM 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wagon-kilometers</td>
<td>97.93</td>
<td>94.38</td>
<td>86.75</td>
<td>93.15</td>
<td>93.75</td>
<td>99.67</td>
<td>99.35</td>
</tr>
<tr>
<td>Wagon-hours</td>
<td>16.68</td>
<td>16.64</td>
<td>16.68</td>
<td>16.30</td>
<td>16.66</td>
<td>17.51</td>
<td>16.27</td>
</tr>
</tbody>
</table>

**LM 1:** Simulation results show that the overall situation has improved. The reduction of stuck wagons means that travel time for certain wagons is reduced, and they reach their destination during the simulation. That could be explained by the introduction of more direct trains and the reduction transshipment times. The KPI wagon-kilometers reduce quite significantly which implies that wagons follow a more efficient schedule. That can also be observed on the reduction of wagon-hours and the big reduction of Tonne-kilometers. Moreover, KPIs wagon-kilometers and wagon-hours divided by wagons transported and by total wagons are also reduced, therefore the efficiency of the movements of the wagons increases. Therefore LM 1 offers a clear improvement on the network in terms of use of resources and efficiency of the network. This modification should be recommended for improving the Swiss SWL network.

**LM 2:** In this case, the number of stuck wagons increases although the number of wagons transported is similar to the original scenario. Some of the travelling wagons do not reach their destination point. Therefore, the modified schedule does not achieve to serve as much stations as the original schedule during the simulation. That is clearly a
negative output. Nevertheless KPIs wagon-kilometers and tonne-kilometers experience a big decrease. Furthermore, wagon-kilometers and wagon-hours divided by wagons transported are reduced. Therefore, the routing of the wagons seems to improve in this scenario. As a result, these modifications of the production schemes have positive and negative outputs and further study is needed in order to decide if they should be implemented.

**LM 3:** The results show an overall improvement of the KPIs. The only negative outcome of LM3 is the increment of stuck wagons. This case should be considered for improving the Swiss SWL network. In order to have an optimal improvement, the exact reasons for the increment of stuck wagons should be identified.

**LM 4:** These modifications increase the use of trains in the network but reduce the transport times and paths of the wagons. It would imply an improvement of service for the client since wagons could be delivered in shorter time, but it would also imply an increment in operational costs. This solution could be adopted if the budget of the operator could be increased.

**LM 5:** In this case, all KPIs improve despite wagon-hours. Therefore, this scenario implies a reduction of costs for the operator. Nevertheless, the increment of wagon-hours could imply a reduction of quality of service from the client point of view. If the increment of wagon-hours is not enough to reduce quality of service for the client, this scenario is close to optimal and the modifications should be implemented on the Swiss SWL network.

**LM 6:** The performance does not vary much from the original scenario since the KPIs related to the trains remain constant, although several trains were removed from schedule in this scenario. Therefore, with a lower number of trains a similar behavior of the overall network is achieved Furthermore, the KPI wagon-hours is reduced, implying shorter transport times for the wagons. Therefore, these modifications should also be considered for improving the current Swiss SWL network.

The results of the simulations show potential improvement in the current Swiss SWL network. LM5 shows the best improvements for reducing operational costs while keeping or even improving the level of performance on the current Swiss SWL production schemes. Second best improvement is LM1, which achieves to reduce a bit operational costs while improving considerably quality of service for costumers. On the other hand LM4 would be only an accepted solution if there would not be budget constrictions on the sector. LM6 introduces some operational improvements when the total number of trains is accounted. LM2 and LM3 need to be further studied or modified to be implemented.

5. Conclusions

Up to now there was no modeling tool that allowed to optimize the different elements of a SWL system: freight planning, train operations, shunting processes and network structure. Although, agent-based approaches to freight simulation were already considered, these were only conceptual papers. Therefore, IVT developed together with Senozon a tool called GüterSim. GüterSim is an agent-based model for modelling SWL networks. Its scalability allows modelling a time-table based freight network, if infrastructure and schedule data are provided. The model has two layers (infrastructure and production) and wagons are routed using an iterative routing algorithm. Data from the Swiss SWL network have been used to develop the model.

A case study is presented to illustrate a possible application of the model. The goal is to prove that GüterSim is a valid tool to discuss possible improvements for a SWL network, given that there is currently a lack of tools to foresee the consequences of modifications on the SWL production schemes. Therefore, six modifications of the current Swiss SWL network are simulated. Two strategies are suggested for the modifications of the current production schemes: bundle train services that serve stations on the same region or bundle train services that serve stations on the same commercial line.

A set of KPI are used to analyze the network performance and discuss the suitability of the modified production schemes modelled on GüterSim: train-kilometres; train-hours; wagon-kilometres; wagon-hours, and tonne-kilometres. The KPIs are used to compare the current Swiss SWL productions schemes and the modifications.
Although the modifications modelled are not optimal (none of them achieves to improve all the KPIs at the same time), results show that improvements on the current Swiss SWL production schemes are possible. Therefore, GüterSim is proved as a valid tool to study the current production schemes and find modifications that improve the performance. Furthermore, as this tool is already built it has no extra cost to use it. Therefore, carrying out case studies in the real network to test their suitability will be always a more expensive option.

Furthermore, GüterSim has a great potential of implementation. It is a scalable agent-based model that only requires schedule and infrastructure data and can be used to model any SWL network. Therefore it could be used to model X-Rail network (European wagonload network). Moreover, it can be used to model any freight network that includes fixed schedule works e.g., intermodal services, inland waterways, etc. Therefore, it is foreseen to further develop GüterSim and apply its potential in other networks.

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References