Decision Support Tools for Customer-Oriented Dispatching

Claus Biederbick and Leena Suhl

University of Paderborn, Decision Support & OR Lab and
International Graduate School for Dynamic Intelligent Systems
{biederbick,suhl}@dsor.de

Abstract. Unavoidable disturbances induce the necessity of operations control and dispatching tasks in the timetable-driven rail traffic. Therefore, dispatching becomes one of the most relevant challenges for the economic success, since it directly affects the timeliness of passengers, which is a core indicator of customer satisfaction. Thus, the integration of passenger preferences into dispatching strategies is a reasonable extension of conventional dispatching algorithms. In this paper we discuss decision support tools to be used by dispatchers in order to achieve customer orientation. The tools are based on an agent-based simulation system modelling the complete German railway network with about 30000 trains and millions of passengers per day. We report tests of various dispatching strategies considering passenger information and aiming to reduce passenger waiting times. We show that even simple heuristics produce better results than the rule based dispatching strategies currently in use.

1 Ideas and Basics of Customer-Oriented Dispatching

Unavoidable disturbances induce the necessity of operations control and dispatching tasks in timetable-driven rail traffic. Dispatchers of a railway have to make decisions about changes to the original train schedule often in a matter of minutes.

Traditionally, railways often emphasise timeliness of trains and cost minimisation within the dispatching process. However, this tends to be suboptimal from the customer point of view. We argue that timeliness of customers is more important for the long-term economic success of a railway than timeliness of trains.

With customer-oriented dispatching we mean dispatching strategies that give customer timeliness a higher priority than train timeliness. Obviously, we first have to determine measures how to judge customer timeliness, which certainly means different things to different people, thus being an extremely multi-faceted and complex aspect.

Mainly, there are two different aspects of customer oriented dispatching: a) regarding wishes of passengers in the dispatching process through usage of passenger information, and b) proactive and individualised information of passengers using modern communication networks and mobile technology like cell

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phones, personalised digital assistants (PDA) or so called "smartphones" which are widely spread within industrialised countries.

Both aspects can be implemented and established independently, but obviously they are closely related: The more information there is available, the better the quality of dispatching that can be achieved. In this paper, we focus on aspect a), because it seems to us that there is a lot of room to improve dispatching quality even with little information about passengers.

Although customer orientation is getting more and more important in the competitive passenger traffic market, little is known about how to reliably measure customer satisfaction in railways and how to design dispatching strategies that maximise customer satisfaction. There are several established simulation tools available for railway traffic (cf. [12], as an example), however, they are usually technology-oriented aiming at optimal dispatching of trains and other equipment. In this paper, we show how simulating railway traffic in a complex network using intelligent software agents results in real-time decision support tools significantly enhancing the on-trip support for passengers thus reducing unscheduled waiting times during their trips. Furthermore, we show how the simulation system can be used to figure out good online-dispatching strategies in order to maximise customer satisfaction.

With "dispatching strategy" we mean every algorithm capable of calculating dispatching decisions consisting of waiting instructions for single *connecting trains* waiting for late *feeder trains* in case of a *connection conflict*. In other words, a train – the feeder – is delayed by a disturbance and could not reach its scheduled connectors in time. If a connector does not wait for the corresponding feeder, all transit passengers of this specific connection will be delayed, if it waits, all passengers in the connector get into the risk of missing their connections.

The implementation and test described in this paper were carried out with data from Deutsche Bahn AG. The complete German railway network with about 30000 trains and about five million passengers daily was implemented within our simulator. With this system, we were able to test various dispatching strategies considering passenger information and aiming in reduction of passenger waiting times.

Topics related to railway dispatching and reliability have been discussed in literature during recent years (see [2, 5, 6, 7], for example), however, in this paper we take a more explicit view considering customer satisfaction as the main goal of disposition activities.

The paper is outlined as follows: In the second section we describe our agent-based simulation test bed for simulating large railway networks, which leads to a simple architecture of co-operating decision support components for dispatchers. Section 3 describes the enhanced dispatching process and the components necessary for this; Section 4 presents some numerical results. In Section 5 the new information process is described, and in Section 6 we close with some conclusions drawn from extensive experimentation with this system.

2 Intelligent Software Agents for Simulation of Large Railway Networks

A railway as a system consists of autonomous mobile actors, such as passengers, trains, and personnel. The system components act on a stable infrastructure, such as tracks, stations, and so on. A simulator of railway traffic needs to model all relevant groups of actors.

A natural way to describe mobile autonomous components is to use *intelligent software agents*. Software agents are (broadly speaking) computer programs which are able to behave autonomously in a certain sense, interact with other software agents, thus building communities, and move within a digital network [12]. Because there are usually several interacting agents, we often speak about multi-agent systems. It is conceptually appropriate to use software agents to implement a microscopic view of the railway system, because an agent is usually configured to represent a microscopic item like one certain train or station, even one certain customer.

From the computer science point of view, multi-agent technology can be understood as an advancement of object-oriented programming, thus presenting a new programming paradigm. Especially, the concepts of autonomous behaviour and intentionality provide new dimensions to model objects with control functionality; this is not possible with traditional object-oriented programming techniques.

We generally distinguish between two basic variants of architecture models for multi-agent systems: *deliberative* and *reactive* architecture. Agents in the deliberative model behave analogously to expert systems as they are known in artificial intelligence. They possess an explicit symbolic model of their environment, together with logical inference mechanisms in order to be able to derive conclusions and evaluate possible actions. A well-known deliberative agent architecture model is the "Belief, Desire, Intention" model of [1]. Reactive agents react on certain stimuli from their environment with executing specified actions. The easiest ways of implementation are if-then rules, e.g., *if* obstacle ahead *then* go left. Agent goals are not given explicitly, intelligence arises incrementally a non-centralised way, leading to a new modelling paradigm for distributed systems.

In our opinion, the agent concept is very well suited for modelling parallel and distributed simulation systems running on low-cost hardware. Furthermore, the agent concept enables us to integrate (autonomous) real world players, such as customers and dispatchers, trains and stations, and more specialised agents[1], into the simulation, thus supporting customer information and distributed real-time dispatching as well.

Using the agent paradigm, the simulation model was divided into several regions by simply building disjoint subsets of network vertices (e.g. stations) and arcs (tracks) as described in [4,8,11]. Every region contains one dedicated central dispatching agent, each of them assisted by several task agents, e.g.,

[1] The "special agents" will be discussed in forthcoming publications.

for carrying out more complex strategy calculations or to re-route passengers missing their connections (cf. Section 3). Then, the size of a (virtual) region is only limited by the dispatching productivity, i.e., the number of decisions computed per time unit. Of course, the regions should be chosen in such a way that communication costs are low within the cluster, and that there are enough communication resources available for peak demands (many delays in the network causing much dispatching activity).

To ensure consistency, a central data storage for infrastructure data (especially the network topology) as well as timetable data (static and dynamic, i.e., with delays during simulation) were chosen. The system is based on the general system architecture introduced in [10].

Between regions, only border crossing trains and passengers are exchanged. Furthermore, dispatchers can receive expected delays and passenger data from trains in neighbouring regions by asking their "colleagues". This becomes necessary when a connector waits for a feeder train still located in a neighbouring region.

In our simulation model, every complex dispatching strategy is implemented as an agent as well, even when it has no typical agent properties (such as proactiveness or mobility), thus enabling us to use the load balancing mechanisms of the agent-based simulation environment.

The dispatching process is modelled as follows:

- Trains send disturbances occurring on their route to a central server. If a dispatcher has to decide, he will ask this server to receive the latest information.
- A departing train asks the responsible dispatcher for permission.
- The dispatcher computes a decision using different strategies (cf. Section 3) and assisting agents, e.g., the passenger router (cf. Section 4). He also determines whether the train has to wait for some other (technical or security) reason, e.g., congested tracks.
- Resulting decisions will be sent to affected entities in the network, both trains and passengers.
- Additionally, every train and station performs "passenger administration". All passengers are continuously transferred from one administrative unit to the next one during the course of their trip.

Of course, the dispatcher is the core component of this system. From an agent technology point of view he could be regarded as a deliberative information agent. This agent has to watch the state of the network and to act autonomously in case of present or predictable conflicts. Even if no feasible plan (with no missed connections) could be found, the dispatcher can use the passenger router to compute new routes for all affected passengers.

The passenger agents then communicate with their real-world counterparts enabling on-trip-interaction with passengers. In other words, they are the distributed user-interface of the system, giving specific information to "their" passengers on the one hand, and collecting useful data from them to support dispatching decisions on the other.

3 Components of Customer-Oriented Dispatching for Enhancing the Dispatching Process

Each dispatcher in the system is responsible for a disjunctive region of the railway network, calculating dispatching decisions for each train waiting for departure, based on the states of all entities within the system. At first, the dispatcher determines the set of actual and potential, i.e., probably forthcoming, conflicts in the controlled area. Then, the time window in which a solution has to be found is determined implying a set of possible decision strategies. The best strategy builds the recommendation for a human dispatcher if the system is used within real world. If it runs in simulation mode, the best calculated plan will be executed without intervention of a dispatcher.

The internal architecture of the dispatching agent is outlined in Figure 1 It is based on the typical architecture of knowledge based systems. The dispatcher uses the passenger router in two ways:

1) Before a decision is made, alternative routes for affected passengers are determined. If all those passengers can be re-routed, no further delay is necessary.
2) After a decision, the router can be used by the agents representing passengers missing their connection to re-route their owners.

Dispatching strategies are of crucial importance, because they have direct impact on customer satisfaction as measured by delays and missed connections. In order to rate passenger strategies we chose a simple measure which is directly influenced by dispatching decisions: We measured the individual and total passenger waiting time. Although there are many criteria defining customer satisfaction (cf. [9]), we think (passenger) timeliness to be the most important factor.

To properly weight waiting times of customers we have to consider the circumstances under which the waiting takes place. Therefore, we define a parameter called *waiting time quality*: Does the customer wait in the train or at the station? If the latter, what type of station is it, i.e., is there any pastime, or is he or she forced to wait at the perhaps cold and windy platform? A second criterion influencing the quality of waiting time is the type of a trip. Waiting a few minutes longer may not be arduous if the customer is on a holiday trip, while it could be crucial for reaching a business appointment, while in both cases longer waiting times lead to disproportionate annoyances. Thus, passengers should not wait "too long" if dispatching can avoid it. This leads to waiting time costs for each passenger, which could be represented by utility functions (cf. [9]). Many other criteria are possible as well. In reality, the final decision has to be made by the (human) dispatcher: the role of the computer-based system is to provide optimal decision support.

In general, we may categorise dispatching strategies according to the amount and quality of input information they require, as well as according to the art and amount of their running time which may be deterministic or stochastic. Usually, the amount or information required is closely related to the expected running

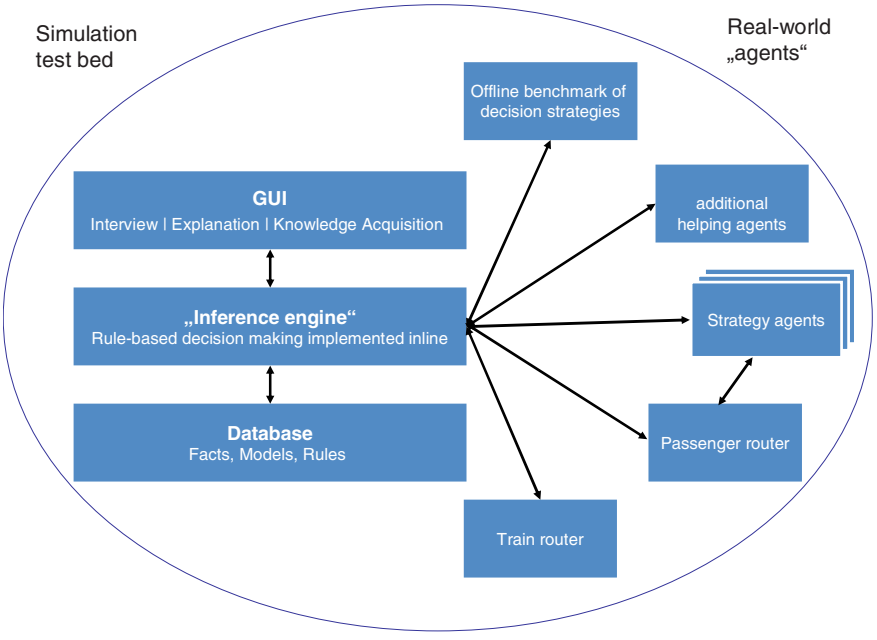


Fig. 1. Internal architecture of a dispatching agent

time. Within the study described in the next section we compared the following basic dispatching strategies:

- General regulations (Do not regard any individualities)
  Strategy #1. Do not wait at all (except for security reasons).
  Strategy #2. Wait until every feeder train has arrived.
- Decisions regarding categories of feeder trains
  Strategy #3. Wait t minutes if the feeder train is of higher category than you. The existing waiting time rules of Deutsche Bahn AG are of this type, too: Only if t is exceeded, a conflict arises and a dispatcher has to decide what to do.
- Time table dependent decisions
  Strategy #4. Wait maximally as long as no connection on the route is endangered considering the scheduled arrivals of your own connectors.
- Decisions including passenger information
  Strategy #5. Wait, if there are "many" changers in specific feeders. This may be compared with the total number of waiting passengers in the connector, e.g., a given rate q is exceeded, where q is (#changers/#waiting passengers). In real world, this information is usually not available. With simulation, however, we are able to show how useful it could be.
  Strategy #6. Variation of #5: Regard the *sum of all changers in all* delayed feeders. If q is exceeded, wait for all feeder trains.

Strategy #7. Variation of #5, but without individual routes. A certain rate of the passengers in a feeder is assumed to change, e.g., based on experienced numbers. This strategy is certainly more easily practicable than the previous ones, because the total number of passengers in a train is fairly easy to estimate.
Strategy #8. Variation of #7 similar to #6.
Strategy #9. Extension of #5: All waiting passengers *at the following* stations are taken into account additionally.
Strategy #10. Extension of #6 in the same way #16 extended #12.
Strategy #11. Extension of #7, again not regarding individual information.
Strategy #12. Analogous to extension of #8.

- Combined strategies
  Strategy #13. Use of passenger router: Wait, if at least one passenger in the feeder could not reach the target station in a reasonable amount of time. For every changing passenger alternative routes are computed. If the estimated new arrival time is close enough to the planned arrival time for all passengers, the connector leaves.
  Strategy #14. Compute the total consequences of both the decision that the connector waits for the delayed feeder and that it does not wait, using online passenger re-routing. Choose the alternative with less accumulated total waiting time along all routes and all passengers.

In order to be able to construct an exact model we would need the specific route of each individual passenger over one day. Since this information was not available, we decided to generate "artificial passengers" based on known information about average train contacts per day. We believe that the approximation is good enough to judge effects of various dispatching strategies.

4 Comparison of Dispatching Strategies

The strategies described above were tested within the simulation environment. The more promising strategies may be suitable for decision support systems for the human dispatcher in real-life situations as well.

Test Environment

The time horizon of the simulation is six hours, i.e., about one million passengers and nearly 9000 trains. Within a simulation run, exponentially distributed delays with expected length of 5 minutes are generated for trains which were chosen arbitrarily. Inter-arrival time of delays is exponentially distributed as well. The delays were chosen in such a way that about 10 % of the simulated trains will be delayed. Note that these are only primary delays; secondary delays could easily be induced by dispatching strategies: a train waiting for its feeders is of course delayed, too.

Our experimentation shows that most simulation runs could be executed in less than two hours on a small cluster of three personal computers (ca. 1.4 GHz

and 512 MB RAM). When the passenger router is in use, it runs on a dedicated computer. One single dispatching decision can be computed in a few seconds, even when more complex strategies are in use. (Of course, run-time is mainly influenced by the calculations necessary for the used strategy.)

Some strategies demand the specification of additional parameters, especially those strategies that integrate passenger information comparing numbers of passengers in trains etc. All simulations were replicated 5 times.

Computational Results

First of all we compared strategies without re-scheduling passengers with missed connections, but penalising a missed connection with a high value in our passengers' utility functions, arguing that a missed connection implies not only delays for affected passengers, but also disproportionately reduces the quality of the product the customer paid for.

Table 1. Percentage of passengers missing a connection in strategies without the passenger router

RWZ	1	2	3	4	5	6	7	8	9	10	11	12
0,59	0,79	6,10	1,58	3,43	0,37	0,38	1,35	0,90	0,36	0,57	0,58	0,70

The percentage of passengers missing a connection in our model is comparatively small; due to the settings of our delay parameters (see Table 1). This is intended, because no valid estimation of this number in reality was available. In this way, we tend to underestimate the real number which was approved by experts of Deutsche Bahn. Therefore, it is unlikely that we overestimate the impact of online passenger re-scheduling.

A comparison of the strategies described above clearly proves our hypothesis, that the strategies including passenger information in many cases achieve much better results than waiting time rules of Deutsche Bahn AG do (see Figure 2). Although the regular waiting time (rwt) of Deutsche Bahn AG performs well, there are strategies integrating passenger information which reduce the weighted passenger waiting time down to about 60 %.

Remarkably, our model showed that rwt in general achieves only about 70 % of passengers reaching their destination on time. Ceteris paribus, passenger-oriented strategies achieved an average rate of about 90 % (with low variance) in our simulation runs.

Impact of Passenger Re-routing

Figure 3 demonstrates the effect of using the passenger router (strategies 13 and 14 obviously cannot be simulated without passenger router). It is obvious that strategies utilising passenger information perform much better than others.

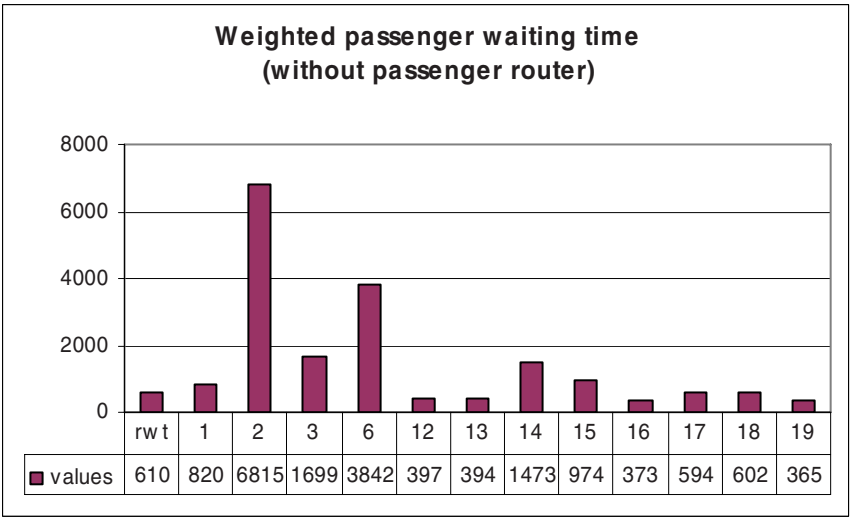


Fig. 2. Weighted passenger waiting time of strategies without using the passenger router

The passenger router clearly is an important part of the system as it is, in a way, the bridge between the two areas of customer-oriented dispatching – a) on-trip information and re-direction of passengers and b) calculating certain strategies. The passenger routing agents were developed jointly with T. Mellouli, J. Goecke, and DB Systems, (system vendor of Deutsche Bahn AG).

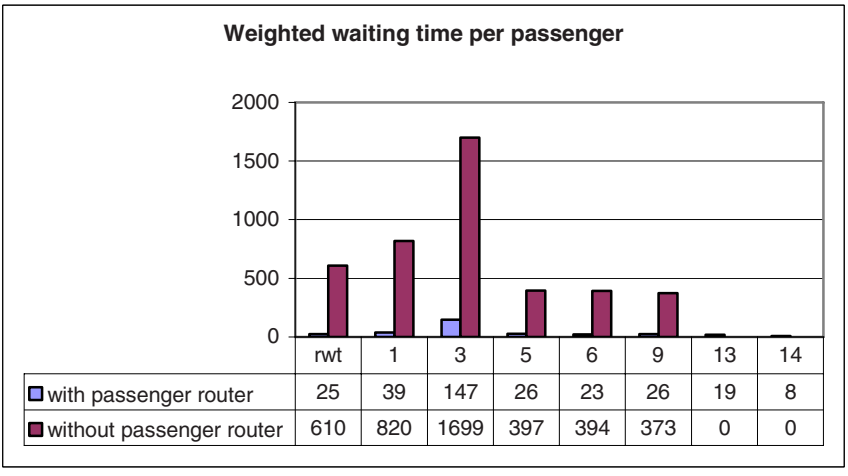
The passenger routers carry out the task of computing alternative routes through the dynamic connection network in case of missed connections. Therefore, a router has to update its internal network model whenever a delay occurs.

There are two ways to use passenger routers in customer-oriented dispatching:

- To determine an optimal passenger re-routing strategy in case of a disturbance taking into account several decision alternatives. Thus, we determine in real-time whether it is better to let some passengers in feeder trains miss their connector or to let some passengers in the connector train miss their connections later on. A dispatching strategy might for example minimise the induced total waiting time in both cases.
- To compute re-routing proposals for passengers already affected by missed connections – this might be helpful for passengers standing on a railway station.

If a disturbance is known before a trip starts, such as the case of a major construction site within the route, the router can be used already before a trip starts.

The internal network representation of a passenger router uses topological sorting and a very efficient update routine. This enables us to include individual



	rwt	1	3	5	6	9	13	14
with passenger router	25	39	147	26	23	26	19	8
without passenger router	610	820	1699	397	394	373	0	0

Fig. 3. Comparison of weighted passenger waiting time with and without passenger router

restrictions during the search for alternative routes, e.g., personalised minimum transit times for passengers, preferred train categories, or minimum number of train changes.

5 Information of and Communication with Passengers

An elegant way to communicate and interact with passengers is to make use of their very own mobile communication devices such as cell-phones (via SMS), PDAs (via Wireless LAN and internet) or all kinds of mobile computers (dito).

For this work we assume these technologies to be wide-spread in industrialised countries. Only this enables us to distribute individualised information and interact with every single passenger on trip and in real time, which can not be achieved using conventional information devices in stations or trains.

We assume furthermore that we are able to track passengers on their routes since we initially know the scheduled route and the position of all trains the passengers use. Even if a passenger is re-routed, it can be argued that the systems advice will be taken thus providing the new position, because he or she wants to reach his/her destination.

The complex task of collecting data of single passengers and their routes is not only helpful for customer-oriented dispatching. It is also very important as a source of information from a strategic point of view, e.g., for facilitating product planning and timetable optimization. The absence of confirmed data made these steps very difficult in the past.

One of the most important applications is *revenue management* (formerly known as *yield management*). In [3] yield management is defined as follows: "yield management is [...] to optimize total revenues at the site where a service

is provided. This optimization is achieved by adopting techniques to manage the capacities marketed by a service company". Deutsche Bahn AG recently tried to introduce some revenue management instruments, e.g., giving special discounts on dedicated trains, so demonstrating their huge interest in such applications.

In our system, every agent with real-world counterpart has a communication interface with its owner, at least on the conceptual layer. This makes it easy to implement this system in real-world contexts: An earlier version of this part of our system was already installed in 2001 in co-operation with DB Systems. Passengers booked the service via World Wide Web and then got information about train states via SMS.

From a technical point of view, our system simply uses existing protocols for communication with passengers as it is shown in Figure 4. Passenger agents just monitor the network status in order to determine whether their principals are affected. If necessary, they just use a conventional web server (farm) as gateway.

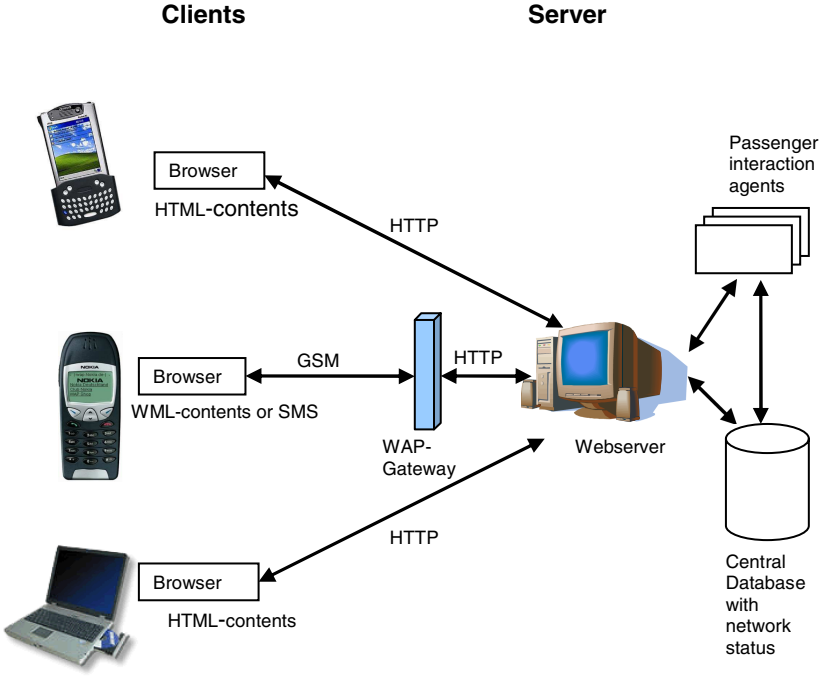


Fig. 4. Technical architecture of the passenger information system

We believe that the huge amount of short messages sent every day proof the ability of such architectures to handle all communication activities in our system, even, if millions of passengers use it.

6 Conclusions

With this paper we show how agent-based simulation under usage of estimated or exact passenger information could be used to improve the quality of the railway dispatching process both for the provider and the passengers.

We have chosen a customer oriented approach, emphasising the timeliness of customers in the connection network: some simple dispatching strategies were presented, proving that even the use of estimated passenger data could enhance the process from the customers' point of view.

However, although the simulation model was validated carefully, it is not totally sure that the presented "best" strategies would perform in reality as well as they do in simulation, because all passenger routes are not taken from real-world data, but generated by an algorithm under certain (plausible) assumptions. Therefore, tests with more reliable passenger data would be necessary to evaluate strategies correctly, i.e., we explicitly do not claim to have determined the best possible strategy, but we provide a system which enhances testing of strategy candidates.

Therefore, modern proactive information systems pushing individualised information are an important field of further research in order to maintain competitiveness of rail traffic providers.

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