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Harnessing Web 3.0 and R to Mitigate Simulation Validation Restrictions

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Abstract: The complexity of modern systems has made the use of simulations paramount, in order to test different scenarios in an affordable, ethical, and risk-free way. As such, simulations need to be validated, ensuring that the obtained results are meaningful. But validation apart from the computational difficulties, bears several other problems. The constant need for validation due to updates on the simulation software, the dependence on the validation experts to be always available for the new iterations and for presenting any new insights are just some of these problems. This paper proposes a framework, and applies it to two case studies, which is based on Web 3.0 technologies and the R statistical language as a mean to mitigate such problems.

1 INTRODUCTION

During the last few decades, systems characterized as Complex Adaptive Systems (CAS) (Axelrod and Cohen, 1999) have become increasingly popular. This complexity, as insinuated by their name, does not arise just from the increase of their size but also from the high level of involvement of humans in many of those systems' internal processes. In turn, since human behavior cannot be characterized as 100% rational, these systems often tend to behave in a seemingly irrational way. Such an example are the decision making processes in areas like healthcare (Rouse, 2008) and transportation (Rinaldi et al., 2001).

The societal and financial impact of decisions made in CAS necessitates for an affordable, ethical, and risk-free way to test potential changes or threats to the system at hand. As such, simulations, which are one of the most popular - if not the most popular - ways of accomplishing that, are deemed to be the most appropriate tool.

Despite the significant help simulations can provide, they should not be, and usually are not, trusted blindly. Simulations should be thoroughly validated, ensuring - at least to some extent - that their results are credible and can be used for the intended purpose. There are multiple methods for validating simulations (Balci, 1998), but these methods are not the only aspect validation success relies upon; the type of validation (Conceptual Model & Operational) (Sargent, 2000), as well as the intended purpose and audience play an important role on how to approach the validation results. This paper is concerned with the operational validation of simulation models (Sargent, 2000), and more specifically with how Web 3.0 technologies and the R statistical language can help mitigate several restrictions that occur during the standard validation life-cycle (Balci, 1994).

More specifically, simulations are characterized by the fact that they regularly need updates either in the form of verification (e.g. debugging), or in the form of conceptual model validation (e.g. improvements in the core algorithms of the simulation model). In turn, following each update, the model should run again in order to assert its operational validation. As a result, a team of validation experts should often be available to perform both the conceptual model and the operational validation (Bergmann and Strassburger, 2010); this substantially increases i. the cost of the validation study, ii. the time between the simulation is finalized by the modelers and the moment it can be used for a formal study, iii. the probability for a human error to occur due to the numerous calculations involved in the procedure (Balci, 1997), and iv. the dependence on specific validation experts, who are knowledgeable of the particularities of the simulation at hand (Balci, 1998).

The conceptual model validation, being a technical area, is quite difficult to automate, albeit not impossible. On the other hand, the operational validation is more straightforward in terms of modeling and automation, since in many cases it utilizes statistical

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techniques. As such, the research question that will be covered in this paper is:

> *Research Question:* How can the operational validation of a simulation model be automated or semi-automated, in order to reduce the time, cost, and human error associated with it?

This paper starts with two assumptions: i. automation, or at the very least semi-automation, can be achieved on an operational validation (hereinafter referred to as validation) study, and ii. Web 3.0 technologies and the R statistical language, given their numerous advantages described in Section 3.4, can be used to accomplish that. The paper aims at answering the research question by first proposing a framework for automated simulation model validation and then demonstrating how this framework was used, in order to automate the operational validation study of two simulation models in the railway sector.

In Section 2, the state of the art on automated simulation model validation is identified. In Section 3, a web-based framework for simulation model validation is proposed. In Section 4, a proof of concept of the framework based on two different case studies is presented. Finally, in Section 5, the future steps are illustrated and final remarks are made.

2 BACKGROUND WORK

Automated simulation model validation is an issue that has increasingly gaining awareness within the simulation community (Balci, 1998). In various areas, automated validation has been proposed and operationalized as a way to mitigate one or more of the risks associated with validation. Studies on automated validation have been performed in the automotive industry (Albers et al., 2012; Kum et al., 2006), in pedestrian simulations (Porzycki et al., 2015), in biological models (Cooper, 2008), even in human-device interfaces (Bolton, 2013). Nevertheless, the amount of research and subsequently the amount of practical applications is still rather limited, and most of the approaches are either domain specific or lack many of the traits that can help mitigate the risks associated with validation, as the latter were identified in Section 1.

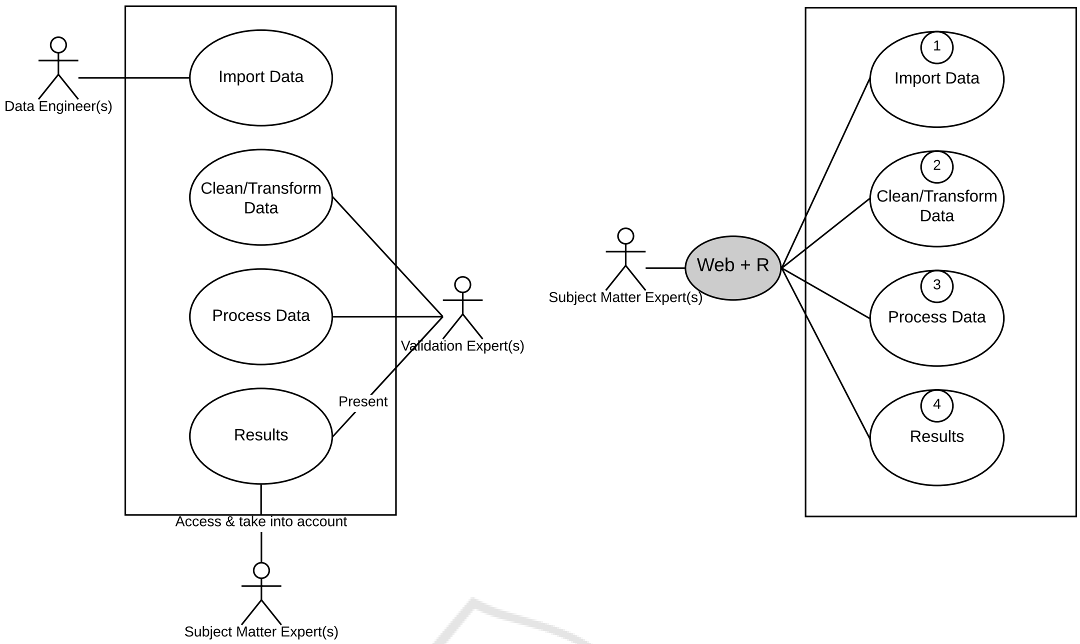
On the other hand, despite the huge influence and usage of the World Wide Web (Chandrasekaran et al., 2002), and consequently of web technologies, to the best of our knowledge, there are no frameworks or tools proposing or supporting the utilization of web technologies for building simulation model validation solutions. While, web technologies have been used widely to build simulation models in various fields (Byrne et al., 2010), their application usually stops after the modeling and before the validation phase. The closest attempt towards a web-based simulation model validation environment has been the Evaluation Environment (EE) (Balci et al., 2002), which is a web-based client/server software system that enables geographically dispersed people to conduct complex evaluation projects in a collaborative manner. Nevertheless, EE is not a validation tool but rather a tool more suitable for complex evaluations, such as modeling and simulation credibility assessment, which requires rigorous collaboration among technical people, subject matter experts, engineers, project managers, and program managers.

The final decision regarding the validity of a simulation model is made by subject matter experts (SMEs). Hence, any tool aimed at helping those SMEs can be considered to be a decision support system (DSS) (Landry et al., 1983). Unlike in simulation model validation, in decision support, web technologies have been used in several different occasions (Bhargava et al., 2007). In particular, the type of DSS that bears a significant resemblance to a simulation model validation process is the model-driven DSS (Power, 2004). A model-driven DSS uses formal representations of decision models and provide analytical support using the tools of decision analysis, optimization, stochastic modeling, simulation, statistics, and logic modeling (Bhargava et al., 2007).

Web-based DSSs, including model-driven DSSs, have experienced a significant increase research-wise in the last decade (Blomqvist, 2014), which is a result of their numerous advantages. The field of simulation model validation could be similarly benefited by web technologies, despite the so far infinitesimal amount of research. The forthcoming sections of this paper demonstrate a framework and two applications of this framework in which the advantages of web technologies for simulation model validation are illustrated and the research question stated in Section 1 is addressed.

3 THE FRAMEWORK

In this section, a web-based framework for simulation model validation is proposed. The framework has three main components: i. the steps taken throughout the standard validation life-cycle, ii. the actors involved in the whole process, and iii. the architecture of the validation tool. In Section 3.1, Section 3.2, and Section 3.3 the three main components of the framework are presented respectively.



(a) Manual validation (b) Automated validation

Figure 1: Use case diagram of the validation life-cycle.

3.1 Validation Steps

Every validation study is different, even if it is about the same simulation software and model. This is due to the multiple elements that define simulations. Depending on the nature of the study, these elements might be the formalism the simulation is based on (Vangheluwe et al., 2002), the fidelity level of the simulation (Liu et al., 2008), the type of the simulation (Constructive, Virtual, Live) (Morrison and Meliza, 1999), to name a few. Despite the uniqueness of every validation study, the steps that need to be taken throughout the life-cycle of the validation are common. Namely, these steps are:

1. **Import Data.** Data from both the simulation and the real system under study need to be imported for further analysis. Data import can be performed in multiple ways. The simplest one is through a user interface (UI), while the most efficient one is by directly running a script in the database. The former is easy but usually extremely slow especially in today's big data era. The latter is fast but requires technical expertise that many SMEs do not possess. Hence, the automation of data import requires a hybrid approach. In the two case studies presented in Section 4, two different approaches are tested.
2. **Clean & Transform Data.** Cleaning data from outliers, thus ensuring accuracy, and transforming data to the same units, thus making data between the model and reality comparable, is usually required. The cleaning and transformation of data can be fully automated, semi-automated, or a combination of both.

   Full automation is implemented for known cleaning and transformation issues, such as converting kilometers to meters or geodesic coordinates to longitude and latitude. Fully automated scripts can run either immediately upon importing the data into the database or after a user's request.

   Semi-automation is implemented when the cleaning or transformation criteria are not predetermined, but instead should be defined by the user. Such an example is the acceptable deviation of GPS data, in which case depending on the study, a user might choose a more strict or more loose threshold.

   Regardless of the level of automation, data cleaning and transformation is a tedious task aiming at ensuring a high quality of data, which depends on multiple criteria (Huang, 2013).
3. **Process Data.** The 3^{rd} step of the validation, the processing of data, is the core of the implementation. This is the step in which the actual validation of the model takes place. It includes the statistical analysis and the design of all the visualizations. In the proposed framework, in this phase, R is used to perform the statistical calculations and create

the necessary graphs.

4. **Present Results.** The last step of the validation study, the presentation of the results, is concerned with how the processed data and the visualizations produced in step 3 are presented to the SMEs. This is the step in which the question: *Is the model valid?* is answered. This question can only be answered in a given context, and presenting the results of the validation study in light of its context to the responsible stakeholders accomplishes that. All three previous steps are preparatory for this phase, in which SMEs can finally assess the simulation results and adjudicate on their validity for the intended purpose of use. While steps 1 and 2 are relatively independent with each other and with the remaining two steps, steps 3 and 4 are closely connected to each other. Design decision made in step 3 pertaining to the statistical tests and the visualizations, are directly affecting the way results are presented to the SMEs and thus, influence not only in terms of content but also in terms of context the final verdict with regards to the validation of the model.

3.2 Actors

In the current manual state of the validation life-cycle, each of the steps identified in Section 3.1 requires one or more actors to perform it and usually more than one type of actors are needed to perform the complete life-cycle (Landry et al., 1983). Depending on the nature and scale of the model, the number of different actors required for the validation of the model can vary. With regards to simulations for decision making, an example of which for the current manual state is shown in Figure 1(a), usually requires three type of actors. Namely, these actors are:

1. Data engineers, who are the ones responsible for fetching the data from the output of the simulation model and provide an environment in which the validation experts can interact with the data.
2. Validation experts, who are the ones responsible for cleaning, transforming, and processing the data providing results for the subject matter experts.Validation experts should have knowledge of the problem domain and expertise in the modeling and validation methodology (Balci, 1998).
3. Subject matter experts (SMEs), who are the ones responsible for evaluating the results provided from the validation experts and deciding about the validity of the simulation model.

While, the SMEs are necessary for the final decision on the validation of the simulation model, the other actors can be potentially omitted from the validation life-cycle. Figure 1(b) shows what the ideal situation of an automated validation life-cycle would look like, which is also the final goal of this paper. In Figure 1(b), the numbers indicate the different steps. These numbers are used throughout this paper to indicate the parts of the architecture and the implementation that correspond to each step. The idea behind Figure 1(b) is for the SMEs to interact as less as possible with the tool during the first three steps and focus mainly on evaluating the results presented to them during step 4. The different levels of automation and the ways to accomplish that are described in detail in Section 4.

3.3 Architecture

The architecture of the proposed web-based framework consists of three main components:

- The web browser, which incorporates the user interface (UI) and is how the SMEs interact with the data and the results.
- The web server, which includes all the web files (e.g. HTML, CSS, etc.), the R scripts, and the necessary interfaces for their communication with the web browser and the database, and
- The database server, which houses the database.

These three main components are the minimum requirements of an implementation based on the proposed framework. Each component can have different *flavors* depending on the nature and the size of the final implementation.

3.4 Advantages & Disadvantages

The utilization of web technologies and R improves multiple Non-Functional Requirements (NFR) (De Weck et al., 2011), also known as *-ilities*. Namely, some of these NFR are:

- **Usability.** Usability is a quality attribute that assesses how easy a UI is to use (Nielsen, 2003). There is an abundance of research and case studies on how modern applications can be user-friendly. Particularly, web content has drawn most of the attention. As a result, building web interfaces has become increasingly more straightforward due to the numerous guidelines, which are also targeted for different user profiles. Hence, a web based system, like the one proposed in this paper, can provide an intuitive UI to SMEs for easily previewing and processing data.

- **Affordability.** Affordability is a collection of attributes, alternatives, and decision-making processes that allow someone to determine if a product is affordable (Bever and Collofello, 2002). A web based system, like the one proposed in this paper, is quite affordable since web tools, like PHP and JavaScript, and R are open source programming languages that bear no cost to license them. Additionally, those tools' popularity makes it affordable to hire or train people, who can then help build and maintain such a system. Finally, such an implementation in which all the complex calculations are performed in the server minimizes the cost of investment in end devices.
- **Portability.** Portability is a measure of the ease with which a program can be transfered from one environment to another (Tanenbaum et al., 1978). Modern devices (laptops, tablets, smartphones) coupled with the responsive design of web content converts these devices into portable working stations. Moreover, due to the fact that all complex calculations can be set up to be performed in the server, even the simplest hardware can be adequate to satisfy a user's needs. Hence, a web based validation system can provide instant access to SMEs regardless their hardware, software environment, or even geographic location.
- **Interoperability.** Interoperability is the ability of different systems and software applications to communicate, to exchange data accurately, effectively, and consistently, and to use the information that has been exchanged (Heubusch, 2006). The specific implementation presented in this paper is an example on the interoperability of web technologies. Web technologies (like HTML, CSS, JavaScript, PHP, SQL) are known for communicating well with each other. What makes these tools remarkable in terms of interoperability is their ability to also seamlessly bidirectionally communicate with external scripting or even programming languages, like it is demonstrated in this paper with R.
- **Accessibility.** Accessibility refers to the design of products, devices, services, or environments for people who experience disabilities (Henry et al., 2014). Internet browsers are increasingly becoming both directly (without assistance) and indirectly (with assistance like screen readers, braille writing devices etc.) accessible to users who experience disabilities. Hence, a web based validation system can enable disabled SMEs to be more engaged in the validation process and offer their expertise.

Along with the NFR, there are also other advantages of using web technologies and R throughout a validation study. These technologies offer high levels of customizability both in the backend and frontend, thus fitting different needs, depending on the simulation at hand. Moreover, the use of Ajax or in the case of R a package like *shiny*, enables to build interactive web applications, where different parts of the data can be used in real-time. Finally, web technologies' and R's versatility promotes both quick prototyping (proof of concept) and full scale commercial implementations with animations, interactive content etc.

Nevertheless, web technologies do have some disadvantages. Web applications, built upon a framework like the one proposed in this paper, do not depend on a local implementation. The browser serves only as the UI for the end user and a server to perform all the calculations is necessary, which means that Internet access is required at all times. A workaround to this limitation is for the end users to have an exact copy of the server implementation in their *localhost* but this requires some level of expertise on managing databases and perhaps web applications in general, as well as it eliminates the portability and affordability advantages. Another drawback of web technologies is that they are still an evolving field. While, there have been major steps forward the past decade, there are still performance issues especially with animated and interactive content.

4 IMPLEMENTATION

In this section, a proof of concept based on the proposed framework for the validation of two distinct simulation models in the railway sector is presented. The models were built to run on two separate simulation environments, FRISO (Middelkoop and Loeve, 2006) and OpenTrack (Nash and Huerlimann, 2004), which are both railway microscopic simulation environments. Thus, they have the potential to, and depending on the model usually do, simulate the railway network in a detailed manner; both have the ability to depict the network down to a switch level. Despite the pointed similarities, these two simulation packages are different, thus suitable for different usages, as revealed by being used in different studies, namely in a punctuality and a conflict detection study respectively. Therefore, the nature of the simulation studies combined with the significantly dissimilar data asked for a diverse approach with regards to their validation. As a result, while the first 2 steps of the validation lifecycle (Data import & Data cleaning and transformation) required similar methods to implement, for steps 3 and 4 two different tools were built. In spite of the use of Web technologies and R on both of them, there was a significant distinction on their design approach.

Web 3.0 technologies include a vast selection of tools and programming languages spanning from frontend to backend. This study and the resulted proof of concept were developed using a MySQL database schema, PHP on the backend, and basic JavaScript with HTML and CSS on the frontend. Therefore, the syntax used throughout this paper will be that of PHP, SQL, JavaScript, shell script, and R. The deployment diagram of the implementation is depicted in Figure 2. The circled numbers correspond to the steps shown in Figure 1(b) and indicate where in the implementation each step takes place.

4.1 Data Import

In this study, two different approaches of data import are tested. The most common file extensions used to import data into a database are the .sql and .csv (Comma Separated Values), thus the subsequent analysis is concerned only with these two extensions.

The first approach is using exclusively the backend programming language of choice. In PHP, for a CSV file, this is accomplished by using the function $fgetcsv()$. In Java, the equivalent is function $Scanner()$, while in Python the module *csv*. Similarly, for an SQL file, this is accomplished by using the function $file\_get\_contents()$. In Java, the equivalent is class *SqlReader*, while in Python the function $read$.

The second approach is using an execution function of the programming language of choice. In PHP, this is accomplished by using the function $exec()$ and executing a shell script. The procedure is almost identical for both SQL and CSV files. In Java, the equivalent for PHP's $exec()$ function is also a function called $exec()$, while in Python the equivalent is subprocess $call$.

In a fully commercial implementation, there are several issues someone should consider, like user permissions, name consistency in the database tables, data sanitization etc., but they are out of scope for the purpose of this paper; hence they are not analyzed further.

Both approaches can be combined with an easy to use UI and they have their advantages and disadvantages. On the one hand, the first approach has the major advantage that it can be sanitized and used safely in the public domain, but at the same time is relatively slow, especially with CSV or SQL files with millions, or even billions, records. On the other hand, the second approach is much faster and should be preferred for large files, nevertheless it is prone to SQL injections making it unsafe for the public domain but suitable for internal use within a company.

4.2 Data Cleaning and Transformation

The proof of concept implemented for this project has a simple UI for cleaning and transforming data and depending on the task at hand, it is a combination of fully and semi-automated cleaning and transformation SQL scripts. In the two case studies examined, five data quality issues were identified. In Table 1, these issues are listed along with an example from the data and the level of automation used to address them.

4.3 Data Processing

Every model, depending on its intended purpose, usually requires different statistical techniques and visualizations to enable its validation. The two examples in this paper are not the exception. Nevertheless, for validating both models, the same tools (HTML, CSS, JavaScript, PHP, SQL, & R) were used and in some cases in the same way. Particularly for this step, the tools used were JavaScript, PHP, SQL, and R. Below, the common usage of these tools on both models is described.

PHP: Used to dynamically load information, like stations, train series etc., from the database and to trigger the R script with the appropriate arguments using the $exec()$ function. In this example, the first argument of the $exec()$ function is a file that allows R to run as a scripting language, the second argument is the R script to be executed, and the rest of the arguments are the ones passed on the script and utilized within it.

JavaScript: Used to dynamically load train series and stations in dropdown menus given previous choices.

R: Used the feature $args \leftarrow commandsArgs(TRUE)$ to fetch the arguments passed from the $exec()$ function in PHP, and the *RMySQL* package to allow to run SQL queries from within the R script (R can also directly interact with NoSQL databases, like MongoDB, using the package *rmongodb*, or Cassandra, using the package $RCassandra - package$).

In Section 4.3.1 and Section 4.3.2 the tools developed to validate Friso and OpenTrack are presented respectively.

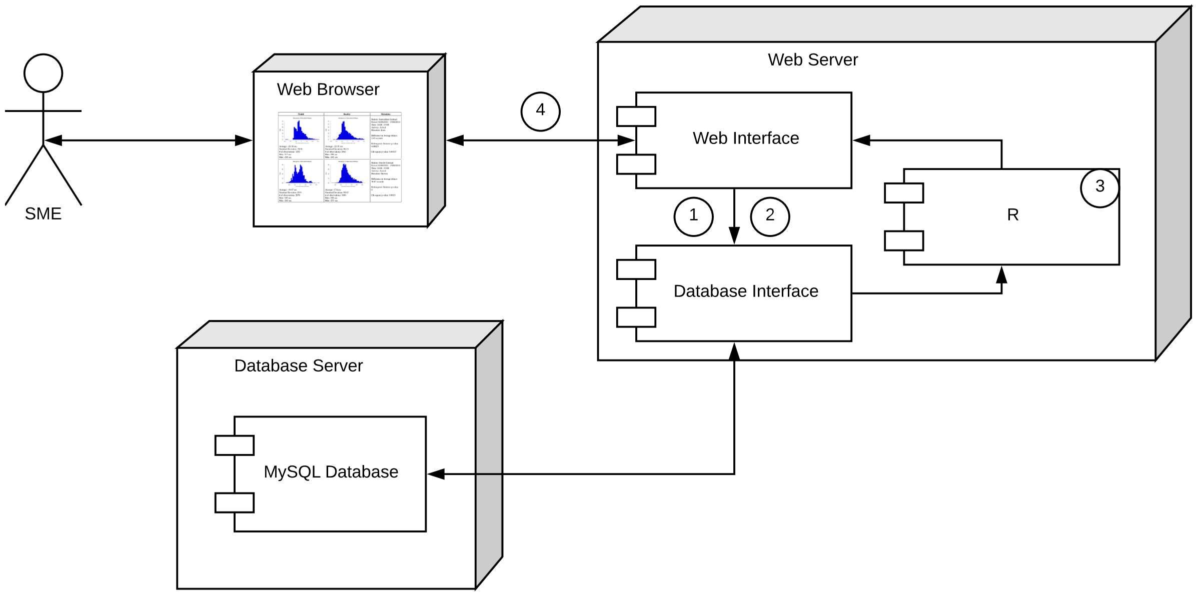


Figure 2: Deployment diagram of the implementation.

Table 1: Examples of data quality problems.

Quality Criterion	Definition	Example	Automation
Syntactic Consistency	The uniformity in the syntactic representation of data values that have the same or similar semantics (Pipino et al., 2002).	Inconsistent: friso.train_series='120NB' operational.train_series=120	Fully Automated
Semantic Accuracy	The conformity of a data value v to its real-world value v' that is considered correct (Fox et al., 1994).	Inaccurate: opentrack.distance=31971.90 operational.distance=33879.40 for acceptable difference $<$ 1000	Semi-Automated
Mapping Consistency	The uniformity in the key values of data representing the same external instance (Price and Shanks, 2005).	Inconsistent: opentrack.position=31971.9 operational.longitude=5.293365 operational.latitude=51.69003	Fully Automated
Semantic Completeness	The degree to which existing values are included in data relevant to the purpose for which the data is stored (Bovee et al., 2003).	Incomplete: friso.arrival='18:42:21' operational.arrival='00:00:00'	Fully Automated
Presentation Suitability	The degree to which the data format, unit, precision, and type-sufficiency are appropriate for the purpose of data use (Price and Shanks, 2005).	Kilometers VS Meters: opentrack.position=0.935898 operational.position=935.9	Fully Automated

4.3.1 Friso

The model in Friso was used to test the punctuality of timetables. As a result, the tool for validating the model should offer a statistical comparison of the delays between the model and reality. Moreover, it should offer a way to perform graphical comparison

(Balci, 1998) of the delays. The latter is needed by SMEs in order to observe how the delays of specific train series or at specific stations are distributed and perhaps cause indirect delays to other trains.

Therefore, the tool incorporates three main components, all in one interface:

1. histograms depicting the delays of both the simulation model and reality in the middle,
2. descriptive statistics (average delay, standard deviation, min and max delay etc.) below the histograms, and
3. metadata (date, location etc.) and tests to verify the equality of the distributions between model and reality (Kolmogorov-Smirnov test and Pearson Chi-square test) on the right.

In R, the function *hist* () was used to build the histograms and the functions *ks.test* () and *chisq.test* () to calculate the Kolmogorov-Smirnov test and the Pearson Chi-square test respectively (In Python, all these function can be found in the package *SciPy*).

4.3.2 OpenTrack

The model in OpenTrack was used to test the conflicts in a timetable. As a result, the tool for validating the model should offer a statistical comparison on the frequency of conflicts between the model and reality. Moreover, it should offer a microscopic visualization of the train driving behavior, which can allow SMEs to pinpoint problematic regions in the infrastructure or the rolling stock.

Therefore, the tool incorporates two main components in different interfaces:

1. a simple UI in which SMEs can identify whether certain conflicts that exist in reality also exist in the model and vice versa, as well as the frequency and the root cause of each conflict.
2. a detailed graph with the driving behavior of the model and reality, including the totality of the realization data and several percentile lines, the number of which varies depending on the observations.

In R, the library *ggplot* was used to build the visualization of the driving behavior (In Python, advanced visualizations can be found in the package *matplotlib*). Additionally, several other libraries were used to fine-tune the graph, like *scales* that allows to automatically determine breaks and labels, and *directlabels* that allows to put a label on a line-graph outside the legend and directly next to the line.

4.4 Presentation of Results

For Friso, a proof of concept of the tool developed is shown in Figure 3, in which case PHP was used to fetch the results of the statistical tests, and HTML & CSS to fetch the histograms and present all the outcomes of the analysis in the most appropriate way. For OpenTrack, which had two different interfaces as mentioned in Section 4.3.2, an example of the resulting graph of the second interface is shown in Figure 4, in which case all the work for the resulting graph was performed in R. For the first interface, PHP, JavaScript, HTML & CSS were used to build the UI, which has simple dropdown menus, and compares the conflicts between the train series from the simulation and operational data.

5 CONCLUSION & FUTURE WORK

In this paper, a framework that combines web technologies and the R statistical language was explored as a mean to mitigate problems pertaining to the validation of simulation models. Web technologies are commonly used in numerous occasions, but there was no indication of them being used in simulation model validation, despite the overwhelming evidence that these technologies can help towards mitigating the risks associated with validation. Indeed, the application of the proposed framework to two case studies showed that web technologies offer a vast toolbox that can help towards developing a more automated validation than the current almost completely manual state. Moreover, the interoperability of those tools further widens the toolbox by enabling more accurate and well-established technologies to be directly implemented within the same environment. The latter is demonstrated in the implementation presented in this paper, in which case R, a well-established statistical language, was used to perform all the necessary calculations and create elaborate graphs, without the end user even be aware of. Finally, the fact that the end result of such an implementation can be presented in a web browser translates not only to easy accessibility but also to an affordable solution regarding the hardware and software of the end user.

A potential threat to the applicability of the framework is the limited focus of the case studies, which were both from the railway sector, and the limited focus on the simulation packages, which were only two, i.e. Friso and OpenTrack. Nevertheless, the data used on both case studies did not have domain-specific or package-specific particularities, which translates

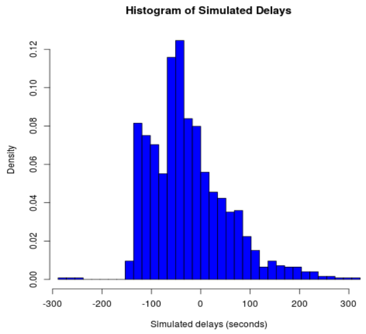
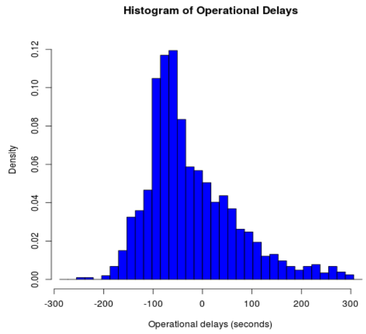
Model	Reality	Metadata
 Average: -25.38 sec. Standard Deviation: 78.56 # of observations: 1252 Max: 315 sec. Min: -282 sec.	 Average: -22.93 sec. Standard Deviation: 90.21 # of observations: 2061 Max: 298 sec. Min: -242 sec.	Station: Amsterdam Centraal Period: 01/06/2014 - 15/06/2014 Time: 16:00 - 19:00 Activity: Arrival Direction: Even Difference in Average delays: 2.45 seconds Kolmogorov-Smirnov p-value: 0.00029 Chi-square p-value: 0.00115

Figure 3: Simulated and real delays in Amsterdam central stations.

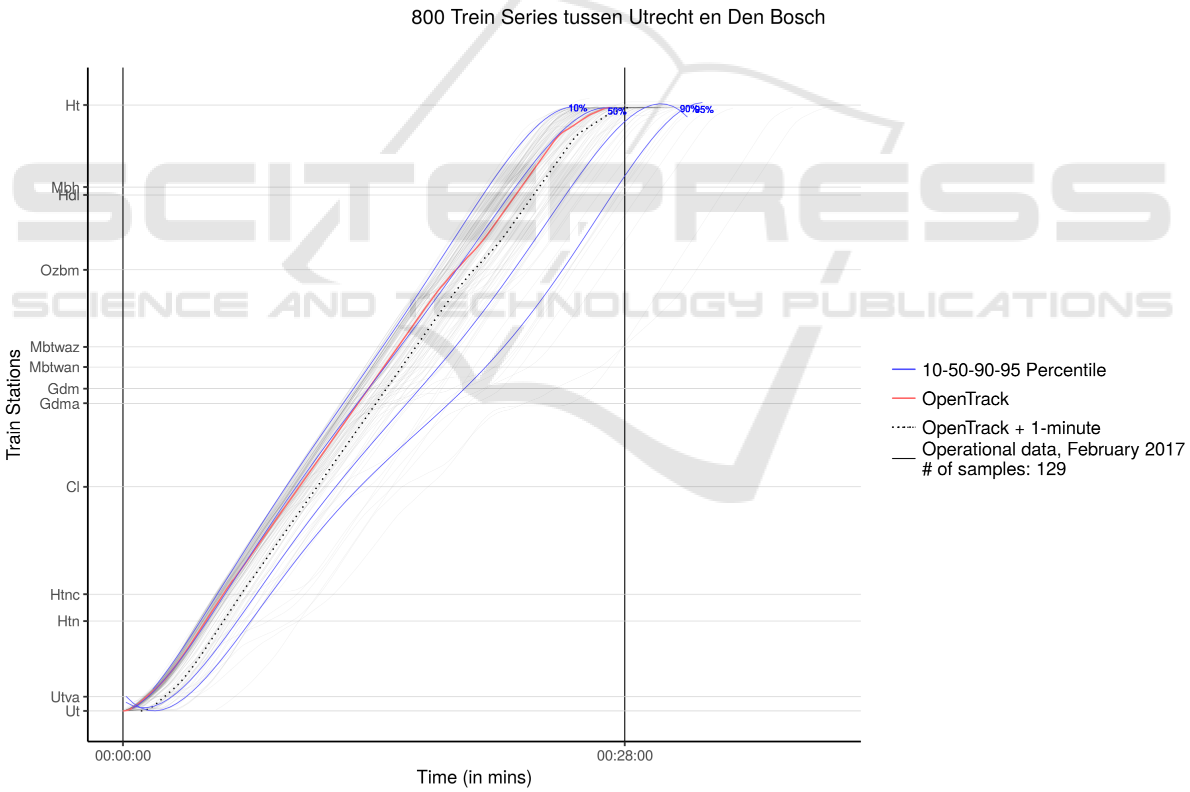


Figure 4: Driving and breaking behavior of OpenTrack.

that the framework is applicable to different domains and simulation packages. By all means, this assessment should not be taken for granted and future work should include the application of the framework to different domains and simulation packages.

Another potential threat arises from the fact that the combination of the particular web tools used in the case studies (PHP, plain JavaScript etc.) and R is not the only way that this system could have been designed. A PHP library for statistics, like *statistics*, coupled with a JavaScript framework for visualizations, like $d3.js$, or an end-to-end solution using Python are also viable and worthy exploring solutions. Nevertheless, this choice was made based on what the authors considered to be the *best tool for the job*, which again should not be considered as a universally best solution. Implementations with different tools, like Java or Python, can lead into a comparative analysis on which tools are preferable for a validation study.

Moreover, in the future, an implementation based on a NoSQL database will provide more functionality with semi-structured and unstructured data, which can enhance even further the applicability of the validation tool. Finally, commercial use of the tool would be possible through a full scale implementation, which will take advantages of a modern JavaScript framework (like Angular.js, React.js, Backbone.js etc.) for a fully customizable user interface, Ajax for asynchronous communication with the database, and more optimized SQL (or NoSQL) and shell scripts for importing, cleaning, and transforming data. Using the aforementioned technologies would benefit modelers, validation experts, and SMEs from developments in other domains, e.g. JavaScript, query optimization etc., hence preventing them from reinventing the wheel and focusing on what is important to them.

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