

Circles Model for Metro Light Rail Analysis

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ABSTRACT

The present article shows a way of transforming a Metro Light Rail simulation model into a more abstract model, based on circles. This sort of representation, which goes into the abstract domain, is made to run in parallel with the common dynamic representation of the rail network during the simulation process, and gives the user precious information concerning the harmony with which the overall system is performing. Frequently, a simple look into this running *circles model* is enough to let the user identify or understand certain traffic effects associated with the accuracy of the vehicle scheduling, for example. Although abstract, this is an interesting representation to help study the dynamics of Metro Light Rail networks, together with other methods like sensitive analysis or the common train schedule or time-space diagrams. We also present some results obtained by simulating a didactic representation of the Metro Light Rail of Brussels, since it is a well-known and modern European Union (EU) light rail facility.

1. Introduction

Since the last decade the boom in urban traffic was slowly transforming into upsetting levels of congestion, stress, daily delays introduced in the movement of millions of people, and ultimately to unbearable levels of air pollution, one can notice a

steady increase in the attraction of the Metro Light Rail as one of the most interesting transport solutions for citizen's flow within and between cities. We can now observe this trend spreading to several places in the world, following the good practice of countries that for a long time already have been prone to using rail transport, such as Germany and France, for example. It is therefore an excellent sign to know that even the emblematic town of Jerusalem is developing its first Metro Light Rail system by now.

It was more or less predictable that with time one should seriously opt for these fairly good quality transport networks in order to reduce not only the environmental impact of people's flow, but also in order to maintain the minimum acceptable quality of life in towns. Too many places in the world are already being confronted with high levels of stress and air pollution, obvious symptoms of a degradation of the life that people live. The price to pay for the compact urban traffic will, therefore, not only be measured in terms of pollution itself, but also, and very importantly, by the health level of the population, since this is the true energy of our towns and cities and the power of our production systems and industry. To replace the myth of comfort of our automobiles for the Metro Light Rail seems an excellent idea, in our opinion.

We have therefore decided to develop a general Metro Light Rail modeller/simulator based on the C++ core code for Supply Chain simulation owned by Feliz-Teixeira (2006), and to upon this create the appropriate interface and the metrics needed to represent and study these types of transportation systems. With such software, several models of real

Metro networks could already be created and tested by simulation¹, making experiments and comparing different policies; for instance, of injecting vehicles in the system. We could also measure some indexes of performance, as well as detect and analyse several unexpected network particularities, like the effect of the operation of terminals or control-lights in the formation of traffic queues, among other effects. All this is contributive to a superior understanding of the entire dynamics related to Metro Light Rail systems, and also to help finding some new ideas about how these systems should be operated. The future inclusion of demand indexes in this simulator is recently being considered, as well.

2. Metro Rail simulation

Although Metro Rail simulation is not a matter frequently seen at academic simulation conferences, perhaps because rail problems and its knowledge seem to be relatively stabilised, several software producers are focused on this subject for industrial purposes, training of rail controllers or of vehicle operators, and even for entertainment. *OpenTrack*, for example, is one of the most attractive Object-Oriented tools belonging to the first group, which is dedicated to modelling and simulating complex rail systems for the industrial level. It is quite user-friendly and was created with the objective of answering questions about rail operations, as mentioned by Huerlimann (2006). Still on relatively the same level but perhaps less sophisticated, one could also point out *RailSim*, for example, from *Systra* (2007), or *RailModeller*, by MacRailSoft for those fond of the Mac Operating System, among others. Deserving reference is also *RailSys*, from Rail Management Consultants GmbH (RMCon), which is part of a more general software system for rail and metro network analysis and implementation (RMCon, 2000?). This tool has extensively been used in projects of Deutsche Bahn, Germany, the European Community, and the Network Rail of the United Kingdom, for example.

Beyond the scope of this article are those systems representing *human-on-loop* (Balci, 2003) simulations or games, as in the case of those tools

dedicated to training operators or to entertain, for instance *PC-Rail*, *Microsoft Train Simulator*, and several others. These tools use very detailed 3D visualizations of the vehicles and the networks, and events are made to happen in the simulation in order to induce the operator to react and learn, a common practice found in flight pilot schools.

3. The *MetroModSim.exe* approach

Although one could say that our approach (see an overview in figure 1) is essentially on the same level as *OpenTrack*, it is being designed to address subjects more related to the tactical and the strategic spheres, instead of simply the operational. *MetroModSim.exe* may also be used to model and analyse some hard operational issues, like the particular operation of a terminus, for example, but at the moment, and due to the fact that our recent work is more directed at the *administrator* of the network instead of its *operator*, this approach seems the appropriate choice.

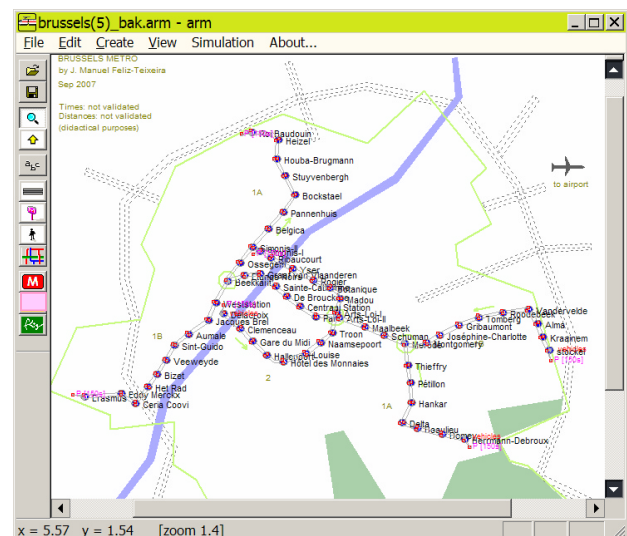


Fig. 1 An overview of *MetroModSim.exe*, showing a representation of the Metro Light Rail of Brussels.

Besides, in this approach we prefer to focus more on the *limits* of the operational, and not in particular on the operational itself, in order to avoid a direct interference with the engineering of the company who operates on the ground (*operator*), who is expected to own the hard operational information about the network and also the real experts on the matter. We therefore may establish the needs, as well as analyse the impact of certain operational policies in the dynamics of the overall

¹ Due to confidential reasons, we may not present here results obtained by simulating a real Metro Light Rail system recently studied by the author, since it is part of his consultancy activity for a private company dedicated to transport systems.

network, but we will always tend to look at the system from an upper perspective, detecting and evaluating its ultimate performances. How is the customer being served; how many vehicles could probably be saved; how many drivers; estimation of the timetables at each of the network nodes; evaluation of the capacities offered; visualization of traffic effects and detecting unexpected delays: all this can successfully be achieved by using *MetroModSim.exe*. We expect to publish more about *MetroModSim.exe* in articles to come.

The *circles model*, anyhow, must be considered a small component of this more general simulation tool, as well as a novel approach for representing *metro-lines* dynamics.

4. The Circles model

Usually, people who employ visual simulation tools have a tendency for representing systems as some sort of scaled models of reality, expecting with this to achieve better conclusions and carry out more perfect analyses. When systems get complex, however, such a mimic representation at the model level may induce in the analyst the same kind of complexity that already impregnates the reality, therefore making him/her somehow blind to the essential. Figure 2, for example, represents the Metro Light Rail of Brussels while being simulated in the standard window of *MetroModSim.exe*.

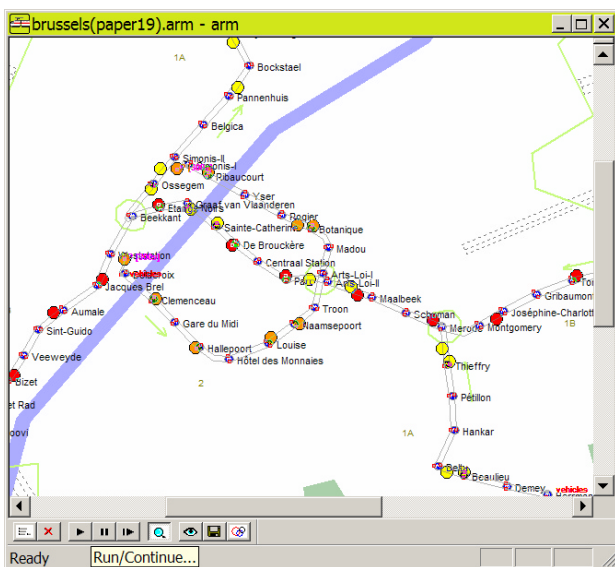


Fig. 2 The standard visual model, while running.

This is an example of the conventional visual representation of a detailed model running in a

simulation window. The network is represented as a net of *arcs* and *nodes* which tend to mimic even the complexity of the space, and the vehicles are coloured circles running along this complex net. In the present case, the vehicles have been distributed by the three *metro-lines* of Brussels Metro²: yellow 1A, which connects Herrmann-Debroux to Roi-Baudouin; red 1B, connecting Stockel to Erasmus; and orange 2, around the city centre, linking Delacroix to Simonis.

When the simulation is running, the complexity emerging from this network becomes evident to the eyes of the observer, as one may easily understand from inspecting figure 2 again. In reality, since this kind of *view* mimics also the horizontal geography of the terrain, a clear relation between the diverse vehicles operating in the various *metro-lines* is not easily achievable, since it is obscured by the complexity of the terrain. This is, without any doubt, an excellent representation for detecting bottleneck effects, for example, and in many cases for understanding the behaviour of a certain light-control at a node, for instance, but it fails to give the analyst a more global view on the dynamics of the system, that is, an impression of the global balance/imbalance ratio of the operations. A judicious manager should have access to tools giving him/her such a global perspective on the operations space, since managing the system's parts is obviously not the same as having a wider view and a good understanding of the entire system.

The *circles model* is a method for avoiding such a tendency and to search for more abstract behaviours, or the "laws" which rule the system's complexity. We may consider that this is *projecting* reality onto the *abstract domain*, the domain of the "laws", or, if we are allowed to be a bit more dramatic, the "God's view", free of any superfluous geographic constraints.

So, if we exercise our minds in order to imagine that in effect a Metro network can be seen as a group of different *metro-lines* which may probably interact with each other at certain common points, or nodes, and if we also look at each of these

² This model was built with data collected from the Internet webpage of the Brussels Metro Light Rail, but the times and the distances are not real, since they were not crucial for the didactic purpose of this article. Therefore, they have been simply and roughly estimated.

metro-lines as a circle, which starts at *terminus#1*, runs to *terminus#2*, and again returns to *terminus#1* in order to reinitiate a new cycle of transport; instead of representing the network as a scaled version of geographical paths and points, as previously, we may represent it as a group of running circles, as shown in the next figure.

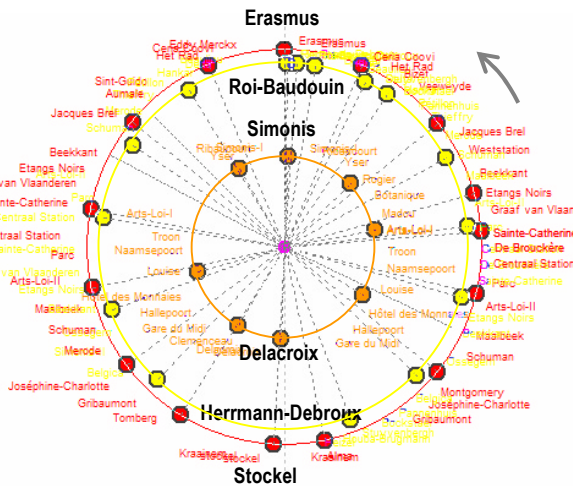


Fig. 3 The Metro Light Rail of Brussels, represented as a model of circles, using MetroModSim.exe (3 metro-lines).

These circles, each of which stands for a *metro-line*, with a perimeter directly proportional to the distance of going and returning to the main terminus (*terminus#1*), will sustain the vehicles moving during the simulation in each of the corresponding *metro-lines*. It is therefore extremely easy not only to understand how the overall system is performing, but also to detect any asymmetry induced by some sort of event or procedure, like a deficient operation at a terminus, for example. In effect, one can easily perceive from figure 3 that all *metro-lines* seem relatively well balanced, with their vehicles similarly spaced between each other, which means good stability in the frequency offered to the customers; even if there will probably be some agglomeration in the “*yellow 1A*” line in the access to Roi-Baudouin. The “*orange 2*” line, however, operating with only 8 vehicles, appears slightly imbalanced, since there are some “empty” spaces between certain vehicles. Due to this fact, we may expect less stability in the frequency offered in this line. Notice that the number of vehicles injected in this model has been estimated for the purpose of this article, so it does not probably express the real conditions of operations on the ground. A serious analysis would, of course,

require collecting and validating the appropriate data.

Mathematically, however, there are also some interesting results emerging from this *circles model* point of view, like the calculation of the *optimum number of vehicles* that should be injected into a certain *metro-line*, the calculation of the frequency change effect when changing the length of a *metro-line*, how balanced the network is performing, etc., but we expect to treat these mathematical aspects in some articles to come. For the moment, we would simply present some more considerations about the “*orange 2*” *metro-line* of the Brussels network.

5. The *orange 2* imbalance, and its correction

As an exercise, we invite the reader to focus the attention on the “*orange 2*” line, which dispatches people around the city centre, as one can see from figure 4.

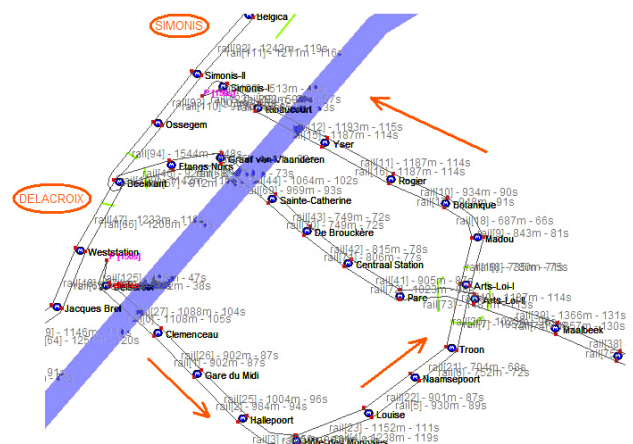


Fig. 4 The *orange 2* line, serving the centre of Brussels.

In order to better illustrate the idea of the *circles model*, and to make some experimentations by simulation, we have decided to model this *metro-line* with origin in Delacroix (*terminus#1*), where the vehicles have been injected, and with destiny Simonis (*terminus#2*), where the vehicles were to invert in order to start operating in the opposite direction. After some rough calculations we have chosen to inject 8 vehicles into this *metro-line*, separated by around 7,5 minutes, as a first bet. The simulator was then made to run for nearly 3 hours of operations, leading to the following frequency figure offered to the customer:

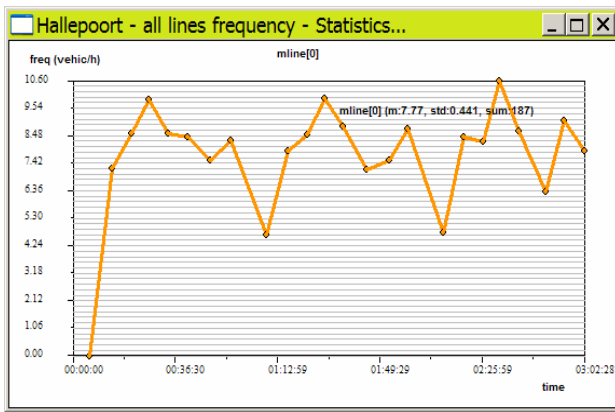


Fig. 5 Frequency offered to the customer (*orange 2*).

This means that an average of 7,8 vehicle/hour could be expected by the customers of this *metro-line*, with a deviation of $\pm 1,8$ vehicle/hour (in a 4 σ confidence interval).

But, if we now inject one more vehicle into this same *metro-line*, the resulting *circles model* already shows a better balanced situation (see Fig. 6).

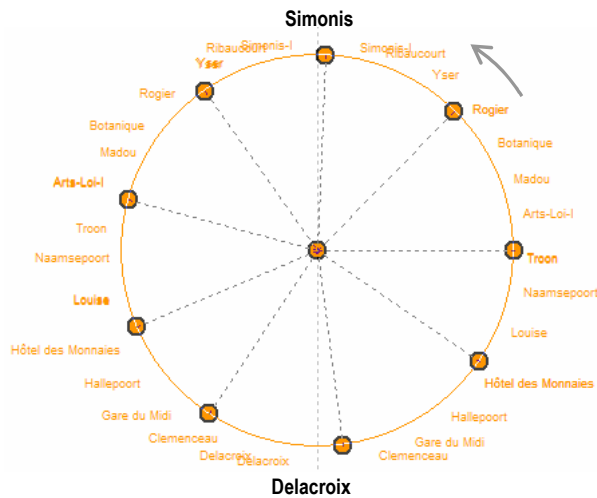


Fig. 6 Circles model of the *orange 2* line, operating with 9 vehicles separated by nearly 7,5 minutes.

At the same time, an obvious and slight increase in the frequency offered to the clients was also observed, as shown in figure 7.

This simple example makes clear the potential available in the *circles model* method for analysing not only a metro network but also several others transport systems. We expect to soon also apply it to bus and rail simulation, for example, and probably it will even make sense to use it in airport and pedestrian studies.

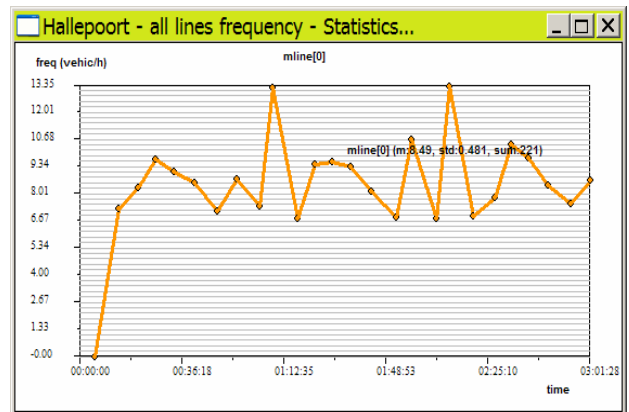


Fig. 7 Resulting increase in the frequency offered to the customer, in the *orange 2* line.

We believe, however, that the perspective of *projecting the reality onto the abstract domain* is the most important idea contained in the *circles model*, since it may be an excellent way to try to understand the complexity of the systems we operate and that surround us.

6. Conclusions

The results obtained in several practical studies, and in particular with the didactic simulation of the Brussels Metro Light Rail presented in this article, are leading us to believe in the great utility of the *circles model* method. We consider this method a sort of *projection of the reality onto the abstract domain*, and an extremely useful representation to explore and understand the subtle “laws” which frequently impregnate dynamic systems, but can be obscured by an excessive tendency for representing the phenomena simply as they appear to our eyes. We advocate that a better and superior understanding of the complexity can be achieved by looking at the reality in the perspective of a more abstract mindset. In effect, as was shown in this article, a simple look into the running *circles model* of a *metro-line* is frequently enough to let us understand its main problems and identify certain ways to solve them, mostly based on the simpler idea of a *balanced/imbalanced ratio*.

Besides, the *circles model* view is also leading us to understand that a *metro-line*, like a bridge or a molecule, has a certain *proper frequency* for being operated, which may be seen as the frequency to which its imbalance is minimal. More than that will

represent too much pressure on the *metro-line*; less than that will mean too little pressure on it.

Finally, we would be pleased to receive any comments or feedback about any experiments based on these ideas.

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J. Manuel Feliz-Teixeira graduated in Physics in the Faculty of Sciences of University of Porto, Portugal, and received an MSc and PhD from the Faculty of Engineering of the same university. His work has been related to various matters, from optical communications, solar energy and seismology to, more recently, the simulation of complex systems in management science, like warehouse, supply chain, production systems and transport systems. His PhD thesis is on "Flexible Supply Chain Simulation".

References:

- Balci, O. (2003). *Verification, Validation, and Certification of Modeling and Simulation Applications*. Paper presented at the 2003 Winter Simulation Conference, USA.
- Feliz-Teixeira, J. M. (2006). *Flexible Supply Chain Simulation (published thesis)*. Porto, Portugal: Publindustria Publisher.
- Huerlimann, D. (2006). *OpenTrack: Simulation of Railway Networks*. OpenTrack. 2007
- RMCon. (2000?). *RailSys, Timetable and infrastructure management*. Rail Management Consultants GmbH (RMCon). 2007, from http://www.rmcon-australia.com/uber_railsys.html
- SYSTRA. (2007). *RailSim 8 network simulator*. SYSTRA Consulting, Inc., 2007, from <http://www.railsim.com/NetSim.htm>