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RAILWAY TRAFFIC FLOW MODELLING USING BOND GRAPHS

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ABSTRACT : *The research task given in this paper consists in applying a unified and generic language represent the dynamics and the architecture of the network while being based on a graphic tool of modelling: the bond graphs. The graphic properties and structure of this tool make it possible to highlight the phenomena of clogging, inertia, storage and source in the warehouses and to quantify by algebra-differentials equations their dynamic. Moreover, it shows that it's possible to adapt the bond graphs energy field towards a new field which is the railway networks.*

KEYWORDS: *Bond graphs, traffic simulation, railway networks.*

1 INTRODUCTION

The railway networks tacked the most important part of transportation systems. Their constantly improving safety record, makes them a very attractive option compared to other means of transport systems. The owners of the railway network systems are confronted daily with the problems arising from the management of train's flow and the capacity of the railway lines. In order to help the operator in the supervision of these flows for the prediction and the regulation of the traffic, it's necessary to have a dynamic model of the rail network. The models developed in the literature are based on the techniques of scheduling and the management of flows by processing the data resulting from the rail network like a static information system.

A rail network is a whole of railway lines, stations and various technical installations. It is characterised by a certain number of technical standards and of exploitation which can possibly put problems of inter-working in the event of connection between networks. The unification of these standards is a long-term work because it brings into play very important investments, since it's a harmonising question for example the gauge where the load with the axle, without speaking about indication or the power supply. Moreover, the field of management of a network system is characterized by its distributed and opened nature. The distribution of the vehicles, the sensors, strong sensitivity and dependence with external phenomena. Also, the environment of transport is dynamic and dubious. Several parameters must be taken into account in the process of regulation.

The regulation must function in real time in order to control the traffic within a multimode network system and to satisfy the demand as well as possible for applying decisions which relate to mainly the schedules and the routes of the vehicles (HAYAT S., 2003).

The state of the art study (FAYECH CHAAR B., 2003)(LAICHOUR H., 2002)(SAUSSOL B. *et al*, 2000) shows that in the traffic regulation field there are five great models.

The existing models aren't answer completely the problem of the traffic regulation. This is why, we choose the bond graphs tools for modelling the railway network.

2 BOND GRAPH APPROACH

2.1 Presentation (OULD BOUAMAMA B., 2006)

The methodology of the bond graph is imagined by H.Paynter and was formalised by D.Karnopp and R.Rosenberg in the Seventies. It is a language unified for all the fields of physics with its graphic character, it makes it possible to be the support of communication between the specialists in different disciplines. It is founded on a study of the transfers of power within the system studied, and a definition of the assumptions of modelling on physical criteria. It is the intermediate model between the physical field and the mathematical model. This approach allows a functional modelling (bond graph with words), structural thanks to the property of causality and behavioural by the detection of mathematical models directly of the bond graph.All manuscripts must be in English. The use of an automatic spell-checker is advised.

2.2 A new field of application

The tool bond graph proved through many projects that it was able to model the various energy fields suitably. These various fields are governed by many laws and principles which any specialist knows through the laws of physics. In the field of transport, the dynamic behaviour is governed by laws of the management of flows of information or similar to that of the physical systems. By analogy, it is then necessary to define the various elements which carry out the network system. The behaviour of the traffic can be seen as an incompressible fluid which runs out along the pipes. Due to this analogy, traffic is usually described in terms of flow, concentration and speed.

2.3 2.3 Variables of the study

In order to study the rail traffic, we use the following variables from (LOZANO and al., 2006).

Traffic speed, ***v:*** Average speed of trains in a section

$$v = \frac{1}{N}\sum_{i=1}^{N} v_i \quad (1)$$

v_i the instantaneous speed of each trains and *N* is the number of trains.

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Traffic flow, ***q:*** Number of trains ΔN that cross a section per unit of time ΔT :

$$q = \frac{\Delta N}{\Delta T} \quad (2)$$

Traffic density, ρ ***:*** Number of trains N that are in a control volume L of the track.

$$\rho = \frac{N}{L} \quad (3)$$

A another way to measure traffic density is the inverse of the distance between trains "*l*". Therefore, expression (3) can be written as :

$$\rho_i = \frac{N_i}{L} = \frac{1}{l} \quad (4)$$

Flow: The bond graph flow variable is the traffic flow :

$$f = \frac{\Delta N_V}{\Delta T} = q_V \quad (5)$$

The number of trains per unit of time in a volume control.

$$q_V = \frac{\Delta N_V}{\Delta T} = \frac{\Delta L}{\Delta T} = V \quad (6)$$

The value of the flow variable becomes in this that speed. The time integral of the flow variable, is the displacement "x". The result is the volume of trains.

$$x = \int q_V dt = \int \frac{dN_V}{dt} dt = \int dN_V = N_V \quad (7)$$

Effort variable ***:*** The variable bond graph effort (e) corresponds to the pressure (p) necessary to make circulate the trains on the way. It is the force (F) or the product of the masses of the trains (M_V) by acceleration (a).

$$e = p = F = M_V.a \quad (8)$$

The product of the effort and the flow can be seen like the power developed by the trains circulating on the track.

$$f.e = q.p = \frac{\Delta N_V}{\Delta T} F = \frac{\Delta L}{\Delta T} F = F.v = E \quad (9)$$

Momentum variable ***:*** The traffic momentum, "P" is the effort time integral :

$$P = \int p dt = \int F dt = \int M_V.a dt = M_V \int a dt = M_V.v \quad (10)$$

2.4 Application to the case of shunting

2.4.1 *Presentation of the system*

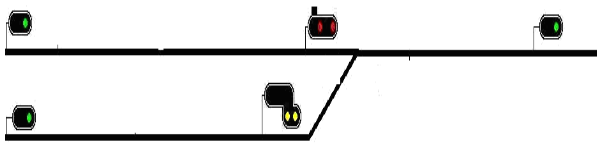


Figure 1. Control volume. Section of three tracks

The system is composed by three ways with indication and a junction. The model of power exchanges is the product of the effort and the vehicles flow. From a source of effort in entry of the system, which can be seen like a pump, it generates a flow. This source of entry is a pressure of vehicles traffic. The variable flow is known as flow of vehicles traffic. This pressure depends on the geometry of the way and of the indications. The resistant element R is dissipative of energy. The birth of a flow of traffic, corresponds to the circulation of trains moving, creates a kinetic energy (element I). Moreover, one leaves the principle of supply and request. However the canton can accommodate only one certain number of it. Therefore, the canton also depends on the capacity of reception (capacitive element C). This one can be seen as the distance from safety between two trains. The end of the way can lead to a station which accumulates the flow of traffic (element C).

2.4.2 *Bond graphs model*

In entry of the two ways, we have two sources of pressure of traffic (pe1 and pe2). That corresponds to an arrival of trains in the ways (can be seen like a pump in hydraulics). The source of effort (pe3) corresponds to the pressure of traffic at exit of way. It is this difference in pressure which involves the circulation of a flow of traffic. The geometry of the way is represented by the element R. The trains moving generate an inertia represented by element I (equivalent with the mass throughput). The lanes answer the criteria of supply and demand represented by the element C (equivalent with a reserve in hydraulics). I.e. the ways can accomodate only one certain number of trains by respecting the criterion of the distance from safety between the trains. Junction 0 represents the meeting of flows of traffic of the way 1 and that of way 2.

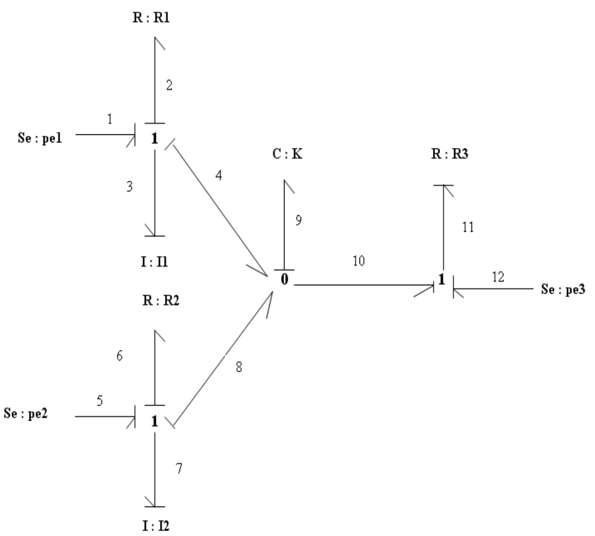


Figure 2. Bond graphs of the shunting case

2.4.3 Estimate of the elements of the model (LOZANO *and al*, 2006)

Traffic inertia : Due to their mass, trains tend to maintain their state of movement or speed. The trains moving generate a kinetic energy.

$$I = M_V \rho L \tag{11}$$

With M_V the mass of the trains, ρ density of traffic and L the length of the way.

Passive resistances : These comprise all physical causes which are opposed to traffic movement : geometry of the way and the state of signalling device.

$$R = (\frac{A}{V_{Max}} + Bv + C\rho) * \frac{1}{b} \tag{12}$$

With A, B and C are coefficients obtained by experimental studies [6]. V_{Max} is the maximum speed authorized on the way and b is a real number comprises into [0,1] which makes it possible to take into account the state of indication. And v is the average speed of trains.

If $b \to 0$ Then $R \to \infty$, traffic light is red.

If b=**1** Then $R = (\frac{A}{V_{Max}} + Bv + C\rho)$, traffic light is green.

Else $R = (\frac{A}{V_{Max}} + Bv + C\rho) * \frac{1}{b}$, traffic light is orange.

Traffic stiffness : Due to an accumulation of trains in the control volume. This accumulation means that there is a storage of potential energy.

C = K (13)

If **l>lo** then **K = 0**

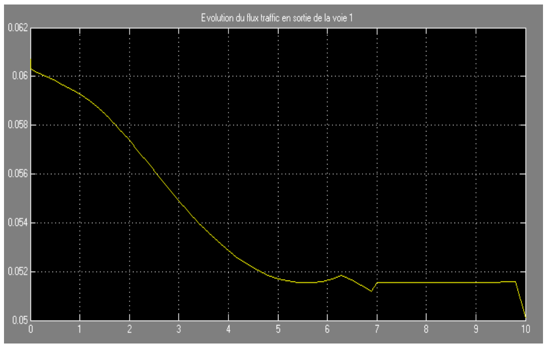
If **l=lo** then **K=** $\frac{lo - l}{l}$

With l the distance between trains and lo the distance from safety between trains.

3 SIMULATION AND RESULTS

Trains had an unitary mass. The length of way 1 was 18 km and the authorised maximum speed was 250 Km/h. The length of way 2 was 8 km and the authorised maximum speed was 100 Km/h. The trains arrived in the ways 1 and 2 with an unit pressure. Speeds of the trains are variables.

Traffic flow



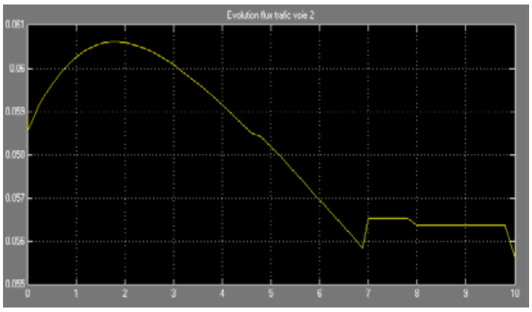
Distance (Km)

Figure 3. Evolution of traffic flow on the way 1

This figure shows a maximum value of flow of traffic which corresponds to the entry of the trains on the way. Then a strong reduction in the flow of traffic until t=3,5s that is due at a mean velocity of the trains which increase, then when speed decreases the flow of traffic starts to increase.

In the same way, this figure shows a correlation between the speed of the trains and the flow of traffic. I.e., when speed increases, the flow of traffic decreases. That is explained by the fact why more speed decreases more the number of trains increase and the density of traffic becomes important. In the same way for the flow of traffic which becomes larger.

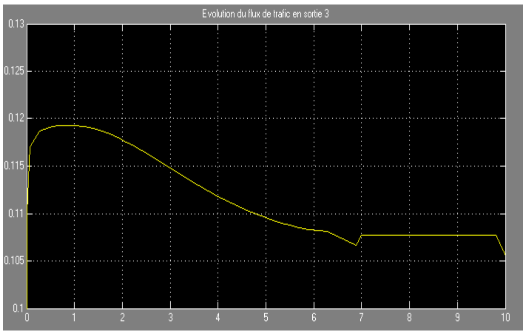
Traffic flow



Distance (Km)

Figure 4: Evolution of traffic flow on the way 2

Traffic flow



Distance(Km)

Figure 5: Evolution of traffic flow on the way 3.

This figure shows that the flow of vehicle traffic on way 3 is the sum of the flow of the vehicle traffic of ways 1 and 2.

We can see here that when signal was red, the flow of traffic was null in way 1. That is translated in simulation by the bit with 0 which causes to make the value of the element R infinite.

The effect of Red light in way 1 was to have on way 3 the traffic flow coming only from way 2. The first analysis of our results reflects the agreement with the reality of the things. After having explained the results obtained of the various tests carried out, we will conclude and give some prospects for our research tasks.

4 CONCLUSION

Some aims was in the work presented in this paper. Initially, the first one was a state of the art of the various existing methods of modelling like some methods of regulation in the course of experimentation. The second aim was to note the limits of the existing methods and to see in what the bond graphs can answer the putting questions of the problems. Knowing that, this application was a first time testing in the railway field. The possibility of directing the bond graphs towards a new field. To analyze a part of the railway system in order to show how modeling bond graph offers interesting prospects associated with the field with transport. Lastly, to give the first approaches of modelling of a part of the rail network.

This modelling is rather centred towards the behaviour of the vehicles traffic flow.

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