

DESCRIPTION

TITLE: Method for characterizing flows between elements of a network

5

The present invention relates to a flow characterization method for characterizing flows between elements of a network. The present invention also relates to an associated electronic flow characterization device.

10

Faced with a situation that is constantly evolving dynamically over time, the operators in charge of controlling flows on a network have a role to play in supervising and analysing unusual phenomena. Such unusual phenomena comprise an increase in demand or saturation on a given route, a drop in demand for transport at a given station or for a given route, failures or accidents involving the means of mobility (trains, metros, buses, bicycles, etc.) or accidents or incidents involving passengers. This role entails taking into

15

account massive volumes of evolving/dynamic data, as well as analysing the said data against sector specific knowledge relating to the structure of the network, the history of the behaviour of agents (users) in this network, external knowledge of the phenomena influencing the network (location, attributes, one-off events, etc.), as well as taking into account possible means of action to resolve or optimise the situation.

20

This operational task is difficult to manage on the basis of simple recordings of passenger flows, which are far too massive to be analysed as such by operators. Tools have therefore been developed in order to reduce the cognitive load on operators, by synthesising the mass of information through the use of analytical tools (that is to say, tools that take into account the data and process that data) and synthetic tools (that is to say,

25

tools that summarise the data and the results of the analysis).

30

In order for them to be usable, these tools are to a large extent automated in terms of data recovery and processing. Most of the proposed systems operate in unidirectional mode: the data are grouped together, analysed, and then a decision is taken or provided in synthesised form to an operator. The systems are therefore either configured entirely in advance, or have a very high (machine) learning capacity, which is difficult to effectuate in practice, particularly in the case of disruptive events (discontinuities) or rare events (no historical examples).

35

It is known from the state of the art that there are expert systems, designed on the basis of human expertise formalised prior to the operation of the system. However, the way in which such systems are designed raises issues relating to scalability in the event of changes in behaviour, the availability of the expert and the design effort required, as well

as the question of the bias introduced by the expert, insofar as the system simply replicates that which is described to it.

Other conventional supervised approaches are based on learning from a learning database. While these systems can be effective when it comes to recognising situations of interest that have already been observed in the history of the network, and can therefore 'filter' events so as to reduce the load on the operator, they still require a historical learning database, as well as references pertaining to normality or abnormality in order to learn (labelling). This again brings up the problem of managing the evolution of the system in the event of fundamental changes in the behaviour of the network (for example, how to manage a new station created on the network), as well as the ability to manage unforeseen or never before observed situations.

There therefore exists the need for means that enable facilitating the characterization of flows on a network.

To this end, the object of the invention relates to a flow characterization method for characterizing flows between the elements of a network, the method being operationally implemented by an electronic characterization device and comprising a configuration phase that comprises the following steps:

- a. the receiving of data in relation to flows between the elements of the network, referred to as flow data,
- b. the displaying, via a user interface, of a representation of the flow data,
- c. the receiving, via the user interface, of at least one user constraint in relation to the grouping of the elements of the network, each user constraint being chosen by a user based on the displayed representation of the flow data, and
- d. the grouping, by a grouping tool, of the elements of the network into groups on the basis of the flow data and the user constraints, with the obtained groups of elements making it possible to characterize the flows between the elements of the network, the elements being equated, for the grouping, to the nodes of a graph and the flows between the elements to the edges of the graph, each group being such that the nodes corresponding to the elements of the group connect to each other in a similar manner and connect in a dissimilar manner to the nodes corresponding to the elements of the other groups.

According to some particular modes of implementation, the method comprises one or more of the following characteristic features, taken into consideration in isolation or in accordance with any/all technically possible combinations:

- the configuration phase comprises, after the grouping step, a display step for displaying, via the user interface, a representation of the obtained groups of elements;

- the method comprises a dynamic monitoring phase that comprises the following steps for each time instant:

- a. receiving of the flow data for the current time instant,
- 5 b. displaying, via a user interface, of a representation of the flow data for the current time instant,
- c. possible updating as necessary, via the user interface, of the user constraints in a manner such that the user constraints of the current time instant are the updated user constraints or else the user constraints of the preceding time instant, and
- 10 d. possible modification as necessary, by the grouping tool, of the groups of elements of the preceding time instant on the basis of the flow data of the current time instant and the user constraints of the current time instant;

- the dynamic monitoring phase also comprises, for each time instant, a display step for displaying, via the user interface, a representation of the obtained groups of elements
15 for the current time instant;

- during each display step for displaying a representation of the obtained groups of elements, also comprised is the display of an indicator relating to the user constraints which have been taken into account in the groupings that have been effected;

- during the step of displaying a representation of the obtained groups of elements
20 for the current time instant, any possible modifications to the groups of elements are prominently emphasised on the displayed representation in a manner that facilitates the management of flows between the elements of the network;

- the dynamic monitoring phase comprises an alert/action generation step for generating an alert and/or for implementing an action when the groups of elements at the
25 current time instant are different from the groups of elements at the preceding time instant;

- the or each user constraint is chosen from:

- a. a constraint in relation to an imposed grouping between the elements of the network, and
- 30 b. a constraint in relation to a prohibited grouping between the elements of the network;

- the grouping tool implements an algorithm such as the expectation-maximisation algorithm.

The present invention also relates to an electronic flow characterization device for characterizing flows between the elements of a network, the device being capable of
35 operationally implementing a method as described above and comprising:

- a. a user interface,

- b. a grouping tool, and
- c. a receiving tool for receiving the flow data and communicating a representation of the flow data, on the one hand, to the user interface and, on the other hand, to the grouping tool.

5 Other characteristic features and advantages of the invention will become apparent upon reading the description here below of embodiments of the invention, given by way of example only and with reference made to the drawings which comprise the following:

[Fig 1], Figure 1, a schematic representation of an electronic flow characterization device for characterizing flows between elements of a network;

10 [Fig 2] Figure 2, a flowchart of an exemplary implementation of a flow characterization method for characterizing flows between elements of a network; and

[Fig 3] Figure 3, a schematic representation of user constraints communicated via a user interface on which the elements of a network are represented.

15 An electronic flow characterization device 10 for characterizing flows between the elements E of a network R is illustrated in Figure 1.

The network R groups together all of the elements E that are capable of exchanging flows with each other. The elements E may be physical entities (objects, installations, etc) or individuals or animals.

20 For example, the network R is a transport network and the elements E are the stations on the network R. The flows are in this case the movements of the means of transport considered between the stations. The transport network is, for example, a rail network (train), a road network (car, bus, bicycle), or indeed even an urban network (pedestrians, scooters/trottinettes). In one example, the stations are self-service rental stations (bicycles, cars, scooters/trottinettes), for which the objective of the operator is to restock the stations based on the traffic, or to detect abnormalities in the rental profiles, for
25 example in the event of a breakdown.

In another example, the network R is a communication network or a social network. The elements E are thus then the users of the network R, and the flows between the elements E are for example the number of interactions between pairs of users over a given
30 time interval.

The flow characterization device 10 is configured so as to operationally implement a flow characterization method for characterizing flows between the elements E of a network R, which will be described in subsequent sections of the description.

35 As illustrated in Figure 1, the flow characterization device 10 comprises a user interface 12, a grouping tool 14, and a receiving tool 16 for receiving the flow data.

The user interface 12 is capable of displaying data and information transmitted by the grouping tool 14 and by the receiving tool 16. The user interface 12 is also capable of receiving data and information originating from the user for transmission at least to the grouping tool 14.

5 The user interface 12 is a human-machine interface. The user interface 12 comprises, for example, a display such as a touch screen or other type, and possibly a keyboard, and/or a mouse.

The grouping tool 14 is capable of determining the groupings of the elements E of the network R, as will be described in subsequent sections of the description.

10 The receiving tool 16 is capable of receiving and communicating a representation of the flow data, on the one hand, to the user interface 12 and, on the other hand, to the grouping tool 14, as will be described in subsequent sections of the description.

The grouping tool 14 and the receiving tool 16 are, for example, software modules, such as computer programme products comprising programme instructions for driving the respective operation of the grouping tool 14 and the receiving tool 16 when such computer programmes are executed by a computer.

For example, the user interface 12, the grouping tool 14, and the receiving tool 16 are integrated into a same given computer. In this case, the computer programmes are for example stored in the memory units of the computer.

20 By way of a variant, the grouping tool 14 and the receiving tool 16 are each integrated into a corresponding computer which is specific to it, and thus form two separate entities.

Also by way of variant, the computer programme products corresponding to the grouping tool 14 and the receiving tool 16 are stored on the same given data medium or on dedicated data media. The or each readable data medium is a medium that is suitable for storing electronic instructions and capable of being coupled to a bus of an IT system. By way of example, the or each data medium is a USB key, a floppy disc, an optical disc, a CD-ROM, a magneto-optical disc, a ROM (Random Access Memory) unit, a RAM (Random Access Memory) unit, an EPROM (Electronic Programmable Read-Only Memory) unit, an EEPROM (Electronic Programmable Read-Only Memory) unit, a magnetic card or an optical card.

A flow characterization method for characterizing flows between the elements E of a network R that is implemented by the flow characterization device 10 will be described here below with reference to the flowchart shown in Figure 2 and the examples shown in
35 Figures 3 and 4 which illustrate certain steps of the method.

The flow characterization method comprises a configuration phase 100 and, optionally, a dynamic monitoring phase 200.

The configuration phase 100 corresponds to the first reception of user constraints as will be described in the section/s here below. The configuration phase 100 thus corresponds to a single time instant. The configuration phase 100 alone corresponds to a characterization of flow at a given time instant.

When it is implemented, the dynamic monitoring phase 200 follows the configuration phase 100 and comprises a number of steps that are repeated over time. The dynamic monitoring phase 200 is thus implemented in real time.

The configuration phase 100 comprises a data reception step 110 of receiving data in relation to the flows between the elements E of the network R, referred to as flow data. The step 110 is, for example, implemented by the receiving tool 16.

The flow data are, for example, derived from measurements carried out on the network R by sensors. The flow data are, for example, a count of interactions or movements between the elements E of the network R.

During the step 110, possibly the flow data received are eventually processed and communicated, as may be necessary, in the form of an adapted representation, appropriate to each of the user interface 12 and the grouping tool 14. For example, the representation communicated to the user interface 12 has been adapted so as to be understandable to a user (see Figure 3 for example) while the grouping tool 14 receives the raw flow data.

The configuration phase 100 comprises a display step 120 of displaying, via the user interface 12, a representation of the flow data. The displayed representation is thus appropriate for viewing by a user of the flow characterization device 10.

The configuration phase 100 comprises a reception step 130 of receiving, via the user interface 12, at least one user constraint in relation to the grouping of the elements E of the network R. Each user constraint is chosen by a user based on the displayed representation of the flow data. Each user constraint is then communicated to the grouping tool 14.

Preferably, the or each user constraint is related to the similarities or dissimilarities between the elements E of the network R.

Preferably, the or each user constraint is chosen from:

- a constraint in relation to an imposed grouping between elements E of the network R, and
- a constraint in relation to a prohibited grouping between elements E of the network R.

Preferably, the user constraints are chosen by the user based on their own knowledge of the operation of the network R, but as well based on the available external knowledge, such as reports pertaining to incidents, or particular events which would lead to occurrences of saturation or closures of certain nodes of the network R.

5 In one of the examples of implementation, the user constraints are already predefined, and the user adapts these constraints (for example via a slider or cursor) in a specific manner for the network R in question.

10 An example of user constraints for a transport network R (metro) is illustrated in Figure 3. In this example, the user interface 12 enables the user to visually indicate the grouping constraints to the algorithm. In this example, the operator is able to easily propose groupings of stations that have identical behaviour (stations encircled with solid lines), or conversely indicate a desire for separation (stations encircled with dashed lines).

15 The configuration phase 100 comprises a grouping step 140 for grouping, by means of the grouping tool 14, the elements E of the network R into groups based on the flow data and user constraints. The groups of elements E obtained make it possible to characterize the flows between the elements E of the network R.

20 In particular, for the purposes of grouping, the elements E are equated to the nodes of a graph and the flows between the elements E are equated to the edges of the graph. The graph is dynamic, that is to say its edges evolve as a function of time, based on the evolution of the flow data. Such a graph is also discretised over time, so as to be able to aggregate the individual transactions in the form of a per interval count. Such a graph is potentially bipartite, in the case where the nodes of the network R are divided into two differentiated groups (for example, a group of entry stations, and a group of exit stations).

25 Each group is such that the nodes corresponding to the elements E of the group connect to each other in a similar manner and connect in a dissimilar manner to the nodes corresponding to the elements E of the other groups. The term "similar" is used to indicate that the connections are close, but not necessarily strictly identical.

30 In one exemplary implementation, this discretised dynamic graph is represented in the form of a sequence of weighted adjacency matrices. An adjacency matrix for a finite graph with n vertices is a matrix of dimension $n \times n$ whose non-diagonal element a_{ij} is the number of edges linking the vertex i to the vertex j . The diagonal element a_{ii} is the number of loops at vertex i (for simple graphs, this number is therefore equal to 0 or 1). Thus, in this example, the inputs to the grouping tool 14 are the adjacency matrices and the outputs of the grouping tool 14 are the reorganised matrices whose rows and columns have been swapped as compared to the input adjacency matrices in a manner such as to make the groups appear.

35

In this example, the nodes of the dynamic graph are the nodes of the network R, and the edges of the dynamic graph at each time instant correspond to an aggregation of the interactions between two nodes over a given period of time. In a transport network R, for example, the nodes of the dynamic graph are the stations of the network R and the edges at a given time instant correspond to the number of trips effected between two given stations over a fixed period of time.

For example, the grouping tool 14 implements a parametric mathematical model that describes the manner in which the flows in the network R are generated, as well as an associated learning algorithm. These parameters (for example: distributions of levels, connectivities, dynamics of transitions etc) are learned by the algorithm on the basis of the data.

For example, the grouping tool 14 implements an expectation-maximisation algorithm, which makes it possible to take user constraints into account. An expectation-maximisation algorithm (often abbreviated to EM) is an iterative algorithm that can be used to find the maximum likelihood parameters of a probabilistic model when the latter depends on latent variables that are not observable.

In one example, an importance indicator is assigned to the user constraints. The said user constraints are then taken into account for the grouping on the basis of the importance indicator. For example, the grouping tool 14 will ensure that there is greater compliance with a constraint having a high importance indicator than with a constraint having a low importance indicator.

Preferably, the configuration phase 100 comprises a display step 150 for displaying, via the user interface 12, a representation of the obtained groups of elements E. The displayed representation is thus appropriate for being viewed by a user of the flow characterization device 10. The displayed representation makes it possible in particular to assist in the management of flows between the elements E, for example in detecting abnormal situations.

Preferably, during each display step 150, also comprised is the display of an indicator relating to the user constraints which have been taken into account in the groupings that have been effected. Thus, in the event of failure to comply with some or all of the constraints, this serves to indicate any potential anomalies in the flow data.

There are therefore two sources of information available to the user:

- The actual flows, synthesised in the form of a real-time view of the network R, and
- The synthesised elements E resulting from the automatic analysis: the partition of the nodes of the network R at each time instant of the study period of the

graph and, where applicable, the parameters of the model estimated by the algorithm based on the data.

As indicated previously, the dynamic monitoring phase 200 comprises various steps that are repeated for each time instant (preferably in real time).

5 The dynamic monitoring phase 200 comprises a reception step 210 for receiving the flow data for the current time instant. The reception step 210 is, for example, implemented in a manner similar to the reception step 110.

10 The dynamic monitoring phase 200 comprises a display step 220 for displaying, via the user interface 12, a representation of the flow data for the current time instant. The display step 220 is, for example, implemented in a manner similar to the display step 210.

15 The dynamic monitoring phase 200 comprises an optional update step 230 of possibly updating, via the user interface 12, the user constraints such that the user constraints of the current time instant are either the updated user constraints or the user constraints of the previous time instant. The update step 230 is, for example, implemented in a manner similar to the reception step 130.

 The update is, for example, due to evolving changes in the network R that are made known to the user, or is linked to the grouping of entities effected at the preceding time instant.

20 The dynamic monitoring phase 200 comprises a modification step 240 for possible modification where necessary, by the grouping tool 14, of the groups of elements E of the preceding time instant on the basis of the flow data of the current time instant and the user constraints of the current time instant. The modification step 240 is, for example, implemented in a manner similar to the grouping step 140.

25 The modifications are, for example, due to modifications in the flow of data and/or to modifications in user constraints.

 The dynamic monitoring phase 200 comprises a display step 250 for displaying, via the user interface 12, a representation of the obtained groups of elements E for the current time instant. The display step 250 is, for example, implemented in a manner similar to the display step 150.

30 Thus, preferably, during each display step 250, also comprised is the display of an indicator relating to the user constraints which have been taken into account in the groupings that have been effected.

35 Preferably, during the display step 250, any possible modifications to the groups of elements E are prominently emphasised on the displayed representation in a manner that facilitates the management of the flows between the elements E of the network R.

Optionally, the dynamic monitoring phase 200 comprises an alert/action generation step 260 for generating an alert and/or for implementing an action when the groups of elements E at the current time instant are different from the groups of elements E at the preceding time instant. The step 260 is, for example, implemented by the user or by the device 10.

Thus, the present method operationally implements an interaction loop between a human-centric system (user interface) and an automated analysis system (grouping tool), with each contributing to the analysis of the other through a common representation mode for representing the relevant information, all in a dynamic manner. By taking user constraints into account, the grouping tool 14 provides the means for facilitating the characterization of flows on a network R.

In particular, the automated analysis sub-system makes it possible to provide a synthesis of the flows on the network R, and, where applicable, of the evolution thereof over time. This synthesis consists in part of the partitioning (clustering) of the nodes of the graph, which is based on a mathematical model of the manner in which the flows are generated, as well as on the information and inputs presented by the operator with a view to making certain partitions of the nodes of the graph less likely than others. In view of the dynamic nature of the partitioning/clustering, the groups that are sought are not necessarily composed of the same nodes over time, and one of the interesting aspects of the analysis is to capture the dynamics of these groups over time. The grouping tool 14 then transmits to the user interface 12 a synthesis of these results.

In symmetrical fashion, the operator-centred part performs an expert analysis based on a graphical representation of the flows synthesised by the automated analysis sub-system, which is possible at a variety of levels of granularity. In particular, dynamic changes in the composition of groups are the main indications that can be used by the operator in order to trigger actions, raise alerts or simply run reports. For example, it may be desirable to raise an alert when a significant number of nodes in the network R change groups between two successive time instants, indicating a significant change in the structure of the flows at a given time instant. However, this phenomenon should be analysed in the light of the dynamics of the evolution previously observed for the nodes in the groups. The results provided by the automatic system to the operator are therefore a series of partitions of the nodes of the graph for each time instant of the dynamic graph as well as the parameters learnt by the model, describing in a synthesised fashion the manner in which the groups of nodes interact and evolve over time. These parameters serve to provide the operator with a better understanding of the results.

In this way, the expert can extract from their analysis insights and indications about current behaviours, and can, if necessary, transmit these in turn to the control system in the form of any potential modifications to the user constraints. In particular, the user constraints describe, for example, spatial, structural or situational similarities between the nodes of the network R, and are likely to change over time on the basis of the operational situation.

Thus, this coupling between the grouping tool 14 and the user via the user interface 12 enables the following:

- a reduction in the biases of the actors (cognitive biases for the operator, learning biases for the control system), and a rapid convergence towards a satisfactory common analysis;
- a strengthening of the level of trust and confidence that the human has in the automatic analysis;
- greater independence from operating conditions and a priori factors than for a supervised analysis (based on a database of examples).

The person skilled in the art will understand that although the invention has been described in particular in the context of transport networks, it is applicable to any graph structure that evolves over time, which can be represented, for example, by a sequence of adjacency matrices, for which the objective is to track changes in the behaviours of nodes (and relationships between nodes) over time.

The person skilled in the art will understand that the embodiments and variants previously described above may be combined provided that they are technically compatible.

12
CLAIMS

1. A flow characterization method for characterizing flows between the elements (E) of a network (R), the method being implemented by an electronic characterization device (10) and comprising a configuration phase that comprises the following steps:
 - a. the receiving of data in relation to flows between the elements (E) of the network (R), referred to as flow data,
 - b. the displaying, via a user interface (12), of a representation of the flow data,
 - 10 c. the receiving, via the user interface (12), of at least one user constraint in relation to the grouping of the elements (E) of the network (R), each user constraint being chosen by a user based on the displayed representation of the flow data, and
 - 15 d. the grouping, by a grouping tool (14), of the elements (E) of the network (R) into groups on the basis of the flow data and the user constraints, with the obtained groups of elements (E) making it possible to characterize the flows between the elements (E) of the network (R), the elements (E) being equated, for the grouping, to the nodes of a graph and the flows between the elements (E) to the edges of the graph, each group being such that the nodes
20 corresponding to the elements (E) of the group connect to each other in a similar manner and connect in a dissimilar manner to the nodes corresponding to the elements (E) of the other groups.
- 25 2. A method according to claim 1, wherein the configuration phase comprises, after the grouping step, a display step for displaying, via the user interface (12), a representation of the obtained groups of elements (E).
3. A method according to claims 1 or 2, wherein the method comprises a dynamic monitoring phase that comprises the following steps for each time instant:
 - 30 a. receiving of the flow data for the current time instant,
 - b. displaying, via a user interface (12), of a representation of the flow data for the current time instant,
 - c. possible updating as necessary, via the user interface (12), of the user constraints in a manner such that the user constraints of the current time instant
35 are the updated user constraints or else the user constraints of the preceding time instant, and

- d. possible modification as necessary, by the grouping tool (14), of the groups of elements (E) of the preceding time instant on the basis of the flow data of the current time instant and the user constraints of the current time instant.
- 5
- 4. A method according to claim 3, wherein the dynamic monitoring phase also comprises, for each time instant, a display step for displaying, via the user interface (12), a representation of the obtained groups of elements (E) for the current time instant.
- 10
- 5. A method according to claims 2 or 4, wherein during each display step for displaying a representation of the obtained groups of elements (E), also comprised is the display of an indicator relating to the user constraints which have been taken into account in the groupings that have been effected.
- 15
- 6. A method according to claim 4 or claim 5 based in its dependence on claim 4, wherein during the step of displaying a representation of the obtained groups of elements (E) for the current instant, any possible modifications to the groups of elements (E) are prominently emphasised on the displayed representation in a manner that facilitates the management of flows between the elements (E)
- 20
- of the network (R).
- 7. A method according to any one of claims 1 to 6, wherein the dynamic monitoring phase comprises an alert/action generation step for generating an alert and/or for implementing an action when the groups of elements (E) at the
- 25
- current time instant are different from the groups of elements (E) at the preceding time instant.
- 8. A method according to any one of claims 1 to 7, wherein the or each user constraint is chosen from:
- 30
- a. a constraint in relation to an imposed grouping between the elements (E) of the network (R), and
 - b. a constraint in relation to a prohibited grouping between the elements (E) of the network (R).
- 35
- 9. A method according to any one of claims 1 to 8, wherein the grouping tool (14) implements an algorithm such as the expectation-maximisation algorithm.

- 5 10. An electronic flow characterization device (10) for characterizing flows between the elements (E) of a network (R), the device (10) being capable of operationally implementing a method according to any one of claims 1 to 9 and comprising:
- a. a user interface (12),
 - b. a grouping tool (14), and
 - c. a receiving tool (16) for receiving the flow data and communicating a representation of the flow data, on the one hand, to the user interface (12) and, on the other hand, to the grouping tool (14).
- 10