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CAUSAL GRAPH CONFIGURATION FOR IMPROVING SYSTEMS MANAGEMENT IN SUPPLIER—CUSTOMER SERVICES

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Abstract: *The paper presents an improved solution for the management of activities for supplied services, as an alternative to the existing results in the literature. An optimization procedure for these usual activities based on the theory of causal graphs is proposed. This approach expresses the connection and interaction between the two main actors, suppliers of goods and products and beneficiaries, consumers of goods and products. The causal graph model is intended for the management of essential activities aimed at the efficient sizing and management of production capacities, supply resources, transport and sales. The initial configuration of this a priori generated graph includes the suppliers and consumers distributed in nodes and the connections expressed by the arcs of the graph. A causal operator is introduced, which allows an efficient computing solution for the supplier-customer services. The location of the customers that can be served by the active suppliers, respectively of the suppliers that must satisfy the requirements of the consumers and the optimal supply route are obtained by using a matrix representation associated with the graph. The solution of the problem is obtained with a minimum computing effort and programming tools.*

Keywords: supplier, customer, graph configuration, causal operator, matrix representation, supply-customer network optimization.

1. Introduction

There were concerns and important results were obtained with reference to the specific problems of the field of management and optimization of the activities of the service provision sector in the supply-customer systems. The interest in finding new solutions remains topical mainly due to the large size and complexity of the network in which the suppliers and consumers of goods and products are involved. Approaches based on modern resources of new information technologies are proposed, in order to improve and increase the efficiency in the management system of the supply-customer structures.

Since the 1960s, G. B. Dantzig and J. H. Ramser have proposed, in *The Truck Dispatching Problem* [1], a procedure for optimizing a vehicle fleet routing

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network for gasoline supply. The aim was to cover a route so that the requirements of each station were met and the total distance covered by the fleet was kept to a minimum. The problem has remained open as it is one that distribution and transportation companies are constantly facing. G. Clarke and J. R. Wright in *Scheduling of Vehicle Routing Problem from a Central Depot to a Number of Delivery Points* [2] in the 1970s developed an innovative procedure for guidance (PO). From a central depot the quantities qj of fuel must be delivered to the points P_j (j = 1… m) using a number of trucks xi with capacities C_i (i = 1… n). It is necessary to minimize the supply costs of refueling stations with a specified geographical distribution. The optimal solution is provided by the use of variable capacities C_i ordered for the available fleet, and the method focuses more on the strategy of loading trucks than on minimizing the distance traveled.

Gilbert Laporte and Yves Nobert in *A Cutting Planes Algorithm for the m-Salesmen Problem* [3] from 1980 presented a mathematical model of **Vehicle Routing Problem** (VRP) defined as an undirected graph G = (V, E) , where V = {0 ,. . . , n} is a set of nodes, each node i ∈ V \ {0} represents a client that has a non-negative request q, while node 0 corresponds to a repository. Each route e ∈ E is associated with a route cost. A fixed fleet of m vehicles each of capacity Q, is available at the warehouse. VRP determines the routes for which the total cost of travel is minimized by respecting the following restrictions: each customer is visited only once on a route; each route starts and ends at the warehouse; the total demand of the customers served by a route does not exceed the capacity of Q. The problem thus formulated is solved by linear mathematical programming techniques. A similar approach is developed in *The Vehicle Routing Problem* [4] and *Bio-inspired Algorithms for the Vehicle Routing Problem* [5] in which the problem (VRP) is formulated and solved by different algorithmic approaches, as a combinatorial optimization problem. *Modeling and Simulation of Macroscopic Traffic Flow: A Case Study* [6] and *An Energy Concept for Macroscopic Traffic Flow* [7] published in 2010 and 2012, respectively, propose modeling and simulation techniques for urban road traffic in macroscopic vision, inspired from fluid flow mechanics. Macroscopic models are used for real-time fluidization by optimal control techniques. Written by Ferrucci Francesco in 2013, *Pro-active Dynamic Vehicle Routing: Real-Time Control and Request-Forecasting Approaches to Improve Customer* [8] addresses issues related to real-time freight forwarding processes of use. Predictive strategies based on stochastic data are presented with the forecast of routes to the likely areas of demand in a proactive manner. Xin Wang in the 2015 publication *Operational Transportation Planning of Modern Freight Forwarding Companies: Vehicle Routing under Consideration of Subcontracting and Request Exchange* [9], proposes solutions for cooperation between modern shipping companies to increase the efficiency of planning operational supply systems sales for benefits. *Metaheuristics for vehicle routing problems* [10] by Labadie Nacima, Prins Christian and Prodhon Caroline in 2016 is dedicated to solving vehicle routing problems by applying metaheuristic techniques or by hybridizing metaheuristic approaches with other types of optimization methods. *Approximate Dynamic Programming for Dynamic Vehicle Routing* [11] in 2017 provides an overview of solving dynamic vehicle routing (SDVRP) methods by stochastic methods and focuses on stochastic dynamic optimization and approximate dynamic programming (ADP). Yihan Liu in his paper *Optimizing the Problem of Home Service Vehicle Tours* [12] published in 2018, highlights how logistics performance and transportation optimization have become important issues in the field of service delivery activities. The paper proposes methods and techniques to increase efficiency and productivity and reduce logistics costs. Computational results with Cplex show us that this problem cannot be solved by exact methods, in a reasonable time, for practical use. It is thus proposed to resort to local search heuristics in order to obtain solutions in a short time and with reasonable computational effort. The proposed solution has been successfully implemented to optimize the routing problem. In *Numerical Control for Hydrodynamic Traffic Flow Models* [13], the authors C. Dimon, G. Dauphin-Tanguy, D. Popescu, IA Tache, present a transport model in road traffic, inspired by the theory of causal graphs, which can be applied with success in supply-customer systems. Mathematical models specific to traffic networks are developed and appropriate control solutions are proposed for positive dynamic systems in order to avoid congestion and increase real-time traffic performance. Vansteenwegen Pieter and Gunawan Aldy in *Orienteering Problems - Models and Algorithms for Vehicle Routing Problems with Profits* [14] from 2019, return to the orientation problem (PO) and extend it to a profit routing problem. In this new routing form each node is weighted with a certain profit and not all nodes need to be visited. In this way, the purpose (PO) is to determine a subset of nodes to visit and the order of visit, so that the total profit collected is maximized and a certain time budget is not exceeded. The latest applications of the optimal routing problem in the fields of supply, logistics and tourism are reviewed.

2. Configuration for the management of supplier-customer service activities

In order to increase the efficiency of provider-customer activities, a causal management model is proposed in the form of a configuration organized on three interrelated levels, namely: estimating the availability offered by the supplier, estimating the requirements of the distribution method and intermediate transport and communication activities, estimating the requirements of the customers (fig. 1).

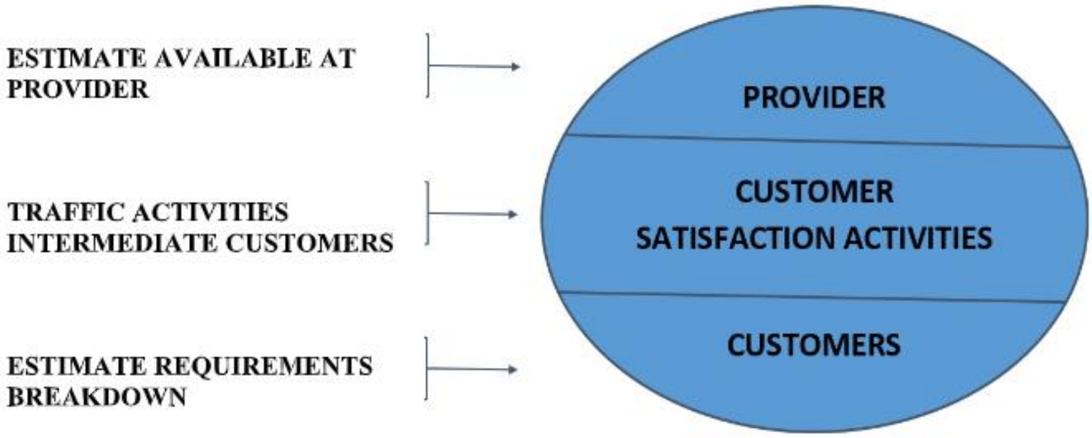

Fig. 1 Management model

This structure can be detailed and supported by concepts and techniques specific to solving the problems of management of supply, production, transport and sales flows, such as:

- elements of automation for the management of service delivery activities.
- traffic assessment and real-time establishment of collection / delivery routes for transport and courier services.

The management model is thus expressed through a causally oriented network, which includes the following objects: suppliers, intermediaries and end customers.

The network is regularly updated according to the service capacity offered by the suppliers and the requirements of the customers.

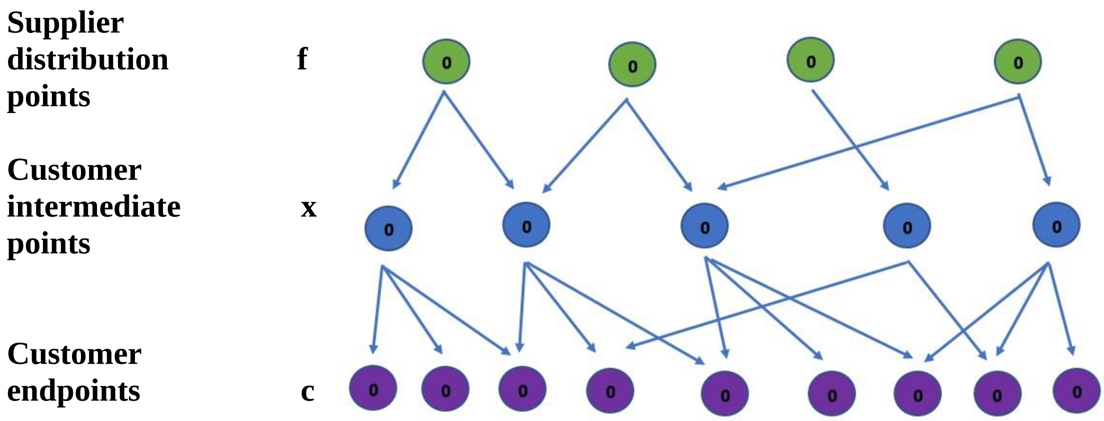

Fig. 2. Causal graph of the service delivery system

The graph in fig. 2 proposes a simple, inactivated structure, organized in a layered configuration: level 1 for product suppliers represented by vector **f**, level 2 for intermediate customers, represented by vector **x** and level 3 for end customers, represented by vector **c**.

Each level contains a number of supplier nodes corresponding to the size of the associated vectors (in the proposed example, level 1 with 4 suppliers involved, level 2 with 5 intermediate customers and level 3 with 9 customers that will be supplied on request).

Graph-oriented connections (graph arcs) represent the causal transitions between levels, ie supply routes, which must be followed by carriers.

The structure of the network is periodically updated according to the service capacity offered by the suppliers, the supply route and the requirements of the customers and can become a large network by increasing the intermediate levels and the size of the vectors **f**, **x** and **c**.

Binary values are assigned to nodes, which mark the activation or deactivation of customers (intermediaries and finalists) and suppliers, as follows:

Nodes f (graph entries) $\begin{cases} \text{0 for inactivated providers} \\ \text{1 for activated providers} \end{cases}$

Nodes x (intermediate states) $\begin{cases} \text{0 for inactivated intermediary customers} \\ \text{1 for activated intermediary customers} \end{cases}$

Nodes c (graph outputs)	{	0 for inactivated end customers 1 for activated end customers

The connections between the nodes represent the traffic routes traveled by the carriers.

Introduce a causal operator **G** that works on the set of components of the vectors **f**, **x** and **c** and associate to the causal graph a matrix representation that allows obtaining the solution of the problem, by going in the opposite direction from the known state of the outputs **c** that represents the customer requirements, to the states intermediate **x**, until the detection of the suppliers from which it must be activated, in order to satisfy the customers' requirements.

For the presentation of the use of the causal model, a case study network is proposed in Fig. 3, which specifies either the availability of suppliers **f** given for exemple by the state of the vector $\mathbf{f}^{\mathbf{T}}$ = [0 0 1 0] or the requirement of consumers, given for exemple, by the vector $\mathbf{c}^{\mathbf{T}}$ = [0 0 0 1 0 0 0 1 0].

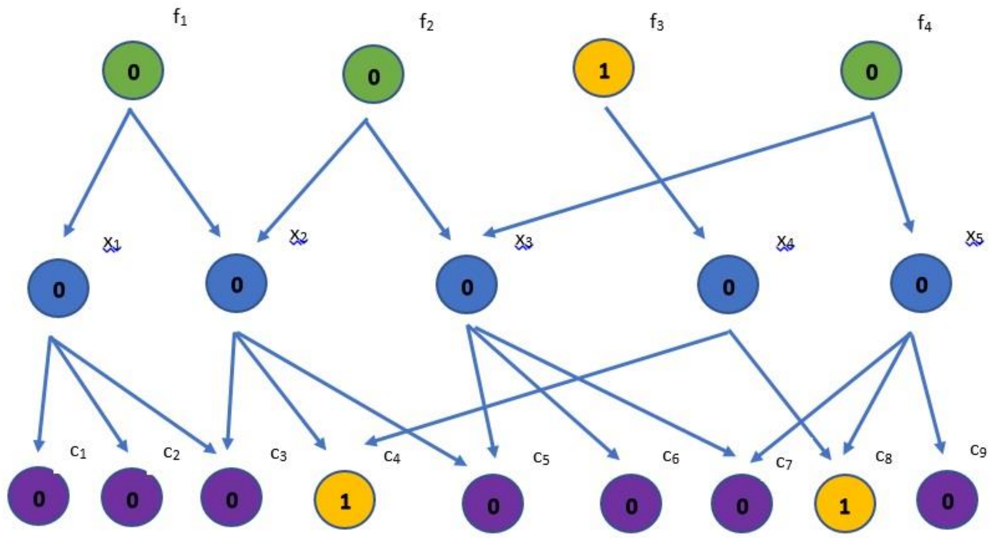

Fig. 3. Causal graph of the service delivery system

With the notations below:

- **f** = vector of distribution nodes SUPPLIERS
- **x** = vector of nodes INTERMEDIATE CUSTOMERS
- **c** = the client of FINAL CUSTOMERS nodes
- **v** = the vector of variables (nodes) in the graph, which gives the size of the graph and is defined as follows:

$$\mathbf{v} = \mathbf{f} \cup \mathbf{x} \cup \mathbf{c} \qquad 1)$$

The route becomes: *Supplier* → *Intermediate client* → *End user* represented by :

SUPPLIERS distribution nodes $\boldsymbol{f} = (f_1, f_2, \ldots, f_p)$
INTERMEDIATE CUSTOMER nodes $x = (x_1, x_2, \ldots, x_n)$
END CUSTOMER nodes $\boldsymbol{c} = (c_1, c_2, \ldots, c_m)$

Relationship (1) can be written on components:

$$(v_1, v_2, \ldots, v_k) = (f_1, f_2, \ldots, f_p) \cup (x_1, x_2, \ldots, x_n) \cup (c_1, c_2, \ldots, c_m \qquad (2)$$

On the set of **v** process variables we introduce the operator **G**, defined as follows:

$$\mathbf{G}(\mathbf{v}) = \{ v_j \mid j = 1, 2, \ldots, s \quad s < k\} \qquad (3)$$

The pair $\boldsymbol{\Gamma} = (\mathbf{G}, \mathbf{v})$ is associated with the path traveled, the set of variables **v** represents the set of nodes implicit in the causal relation given by **G**. For the nodes in the graph we attach the logical states "0" if the variable v_i is not activated and "1" if the variable v_j is enabled in the graph configuration.

By convention we consider that:

- **G** (vi) = represents the set of nodes that are determined by the state of the variable v_i.

- $\mathbf{G}^{-1}$ (v_j) = represents the set of nodes that determine the states of the variable v_j.

To determine the state of a node xi influenced by a collection of nodes ($c_1, c_2, \ldots, c_l$) the following relation is used:

$$x_i = c_1 \cap c_2 \cap \ldots \cap c_l \qquad (4)$$

The state of node xj in the collection ($x_1, x_2, \ldots, x_l$) which determines the state of node c_i, is estimated with the relation:

$$x_j = c_i \cap \left(\bar{x}_1 \cap \ldots \cap \bar{x}_{j-1} \cap \bar{x}_{j+1} \cap \ldots \cap \bar{x}_l \right) \ldots \qquad (5)$$

By the inverse operator G^{-1} (v_j), the state of the node represented by the variable x_i can be evaluated with the relation:

$$x_i = f_1 \cup f_2 \cup \dots \cup f_l \tag{6}$$

The relationship that makes it possible to evaluate the influence between the receiving nodes and the source nodes can be written as:

$$c_j = \cup^n_{i=1} x_i, \ (j = 1, 2, \dots, m)$$
$$x_l = \cup^p_{r=1} f_r, \ (l = 1, 2, \dots, n) \tag{7}$$

3. Matrix-vectorial representation of the causal graph

Using these specifications, we can describe the causal relationships between the variables of the supply-customer system, with the help of a matrix-vector representation. Matrix **A** expresses causal dependence between states **x** and **c**, and matrix **B** expresses causal dependence between **f** and **x**. You can write the relationships:

$$\mathbf{x} = \mathbf{Bf}$$
$$\mathbf{c} = \mathbf{Ax} \tag{8}$$

where,

$$\mathbf{x}^\mathbf{T} = [x_1, x_2, \dots, x_n]$$
$$\mathbf{f}^\mathbf{T} = [f_1, f_2, \dots, f_p]$$
$$\mathbf{c}^\mathbf{T} = [c_1, c_2, \dots, c_m] \tag{9}$$

Matrices **A** and **B** are constructed according to the rules:

- the matrix **A** has the elements obtained by $\mathbf{G}^{-1}$ (c_i), with i = (1,2,…, m) on the line and **G** (x_j), with j = (1,2,…, n) on the column.
- the matrix **B** has the elements obtained by $\mathbf{G}^{-1}$ (x_i), with i = (1,2,…, n) on the line and **G** (f_j), with j = (1,2,…, p) on the column.

For the representation of the graph proposed in Fig. 3, with the help of operators **G** and $\mathbf{G}^{-1}$, the following results are obtained from (10) and (11), causal and anticausal.

$$\begin{aligned}
&G(x_1) = \{c_1, c_2, c_3\}\\
&G(x_2) = \{c_3, c_4, c_5\}\\
&G(x_3) = \{c_5, c_6, c_7\}\\
&G(x_4) = \{c_4, c_8\}\\
&G(x_5) = \{c_7, c_8, c_9\}\\
\\
&G(f_1) = \{x_1, x_2\}\\
&G(f_2) = \{x_2, x_3\}\\
&G(f_3) = \{x_4\}\\
&G(f_4) = \{x_3, x_5\}
\end{aligned} \tag{10}$$

$$\begin{aligned}
&G^{-1}(c_1) = \{x_1\} & &G^{-1}(x_1) = \{f_1\}\\
&G^{-1}(c_2) = \{x_1\} & &G^{-1}(x_2) = \{f_1, f_2\}\\
&G^{-1}(c_3) = \{x_1, x_2\} & &G^{-1}(x_3)=\{f_2,f_4\}\\
&G^{-1}(c_4) = \{x_2, x_4\} & &G^{-1}(x_4) = \{f_3\}\\
&G^{-1}(c_5) = \{x_2, x_3\} & &G^{-1}(x_5) = \{f_4\}\\
&G^{-1}(c_6) = \{x_3\}\\
&G^{-1}(c_7) = \{x_3, x_5\}\\
&G^{-1}(c_8) = \{x_4, x_5\}\\
&G^{-1}(c_9) = \{x_5\}
\end{aligned} \tag{11}$$

With the operational resources introduced above and from the causal inter-influence relations (11) between the vectors **x** and **c** and respectively **f** and **x**, the matrices **A** and **B** necessary to activate the status of consumers / suppliers are calculated.

- the elements of the matrix **A** are:

$$a_{ij} = \begin{cases} 1, \text{ if } x_j \to c_i \\ 0, \text{ if } x_j \not\to c_i \end{cases} \tag{12}$$

- the elements of the matrix **B** are:

$$b_{ij} = \begin{cases} 1, \text{ if } f_j \to x_i \\ 0, \text{ if } f_j \not\to x_i \end{cases} \tag{13}$$

The result is the matrix **A** of dimensions (9x5) and **B** of dimensions (5x4).

$$\mathbf{A} = \begin{pmatrix} 1&0&0&0&0\\ 1&0&0&0&0\\ 1&1&0&0&0\\ 0&1&0&1&0\\ 0&1&1&0&0\\ 0&0&1&0&0\\ 0&0&1&0&1\\ 0&0&0&1&1\\ 0&0&0&0&1 \end{pmatrix} \qquad \mathbf{B} = \begin{pmatrix} 1&0&0&0\\ 1&1&0&0\\ 0&1&0&1\\ 0&0&1&0\\ 0&0&0&1 \end{pmatrix}$$

It is observed that the lines of **A** represent $\mathbf{G^{-1}}$ (c_i) with i = 1, 9 and the columns of A represent **G** (x_j) with j = 1, 5, and the lines of **B** represent $\mathbf{G^{-1}}$ (x_i) with i = 1, 5 and the columns of **B** represent **G** (f_j) with j = 1, 4.

4. Solving the causal graph

Given that the configuration of the graph is given by the vector matrix representation in (14) and the vector **f** is known $\mathbf{f^T}$ = [0 0 1 0], with the relations in (8) we deduce the state of the vector **x** and respectively the state of the vector **c**, ie specified the final consumers to be served by the active suppliers in **f**. By operating with matrices **A** and **B**, the intermediate vector $\mathbf{x^T}$ = [0 0 0 1 0] is obtained and the final result, the configuration of the vector **c**:

$$\mathbf{c^T} = [0\ 0\ 0\ 1\ 0\ 0\ 0\ 1\ 0] \quad (15)$$

Conversely, if **c** is known (end-consumer requirement), it is possible to select the component suppliers of the vector **f** that will serve the end-consumer requirements desired by the consumers in **c**. Now, consider the same structure of the causal graph in Fig. 3 and the state of the vector **c** (supplier requirements), $\mathbf{c^T}$ = [0 0 0 1 0 0 0 1 0].

For the detection of active providers **f**, a matrix representation from (16) is used, as follows:

$$\mathbf{x} = \mathbf{A^t c} \quad (16)$$
$$\mathbf{f} = \mathbf{B^t x}$$

where $\mathbf{A^t}$ and $\mathbf{B^t}$ are the transposes of the matrices **A** and **B** respectively (since the left inverse of each matrix, is given by

$$\boldsymbol{A^{-1} = (A^T A)^{-1} A^T = A^T}$$

and

$$\boldsymbol{B^{-1} = (B^T B)^{-1} B^T = B^T}$$

and the state of the vector **f** is obtained by calculation.

The vector $\mathbf{x^T}$ = [0 0 0 1 0] is thus obtained, taking into account the relations (4), (5) and the final result, ie the state of the vector **f**:

$$\mathbf{f^T} = [0\ 0\ 1\ 0] \quad (17)$$

The customer / supplier specification algorithm, which ensures the efficient operation of the service delivery system according to the requirements of the graph, uses as input data: the causal system structure {**G, v**} and the availability of suppliers (vector status **f**) / customer requirement (vector status **c**), it results:

1. Calculate the matrices **A** and **B** corresponding to the structure of the graph constructed according to the needs of the partners in the supply-customer network.
2. Apply the operator **G** to the known components of the vector **f** and obtain the states **x** associated with the requirement of intermediate consumers; the operator **G** is applied to the components of the predetermined vector **x** and the state of the vector **c** in relation (15) is obtained, ie the customers to be supplied by the suppliers **f** are specified.
3. Calculate the matrices $\mathbf{A}^t$ and $\mathbf{B}^t$ to traverse the graph in the anticausal direction.
4. The operator $\mathbf{G}^{-1}$ is applied to the known components of vector **c** and the **x** states associated with intermediate consumers are obtained; the inverse operator $\mathbf{G}^{-1}$ is applied to the predetermined components x_i and the state of the vector **f** associated with the suppliers is obtained, from relation (17), ie the suppliers are established who must satisfy the initial requirements of the final consumers.
5. Operators involved in the transport and supply of customers shall carry out the specified routes required for the delivery / supply of products.

The causal/anti-causal routes established by the meaning assigned to the arches on the tree, which satisfies the availability of the suppliers, are presented in the image in Fig. 4. The graph solution, obtained in both directions, which ensures the efficient management of the supply-customer system, can be delivered to the user in the form of a dedicated software product. This solution is valid for the period in which the causal graph has been configured to satisfy the management activity of the structure of the supply-customer system. Another supply-and-customer network generates a new graph that is resolved according to the same causal/anti-causal procedure.

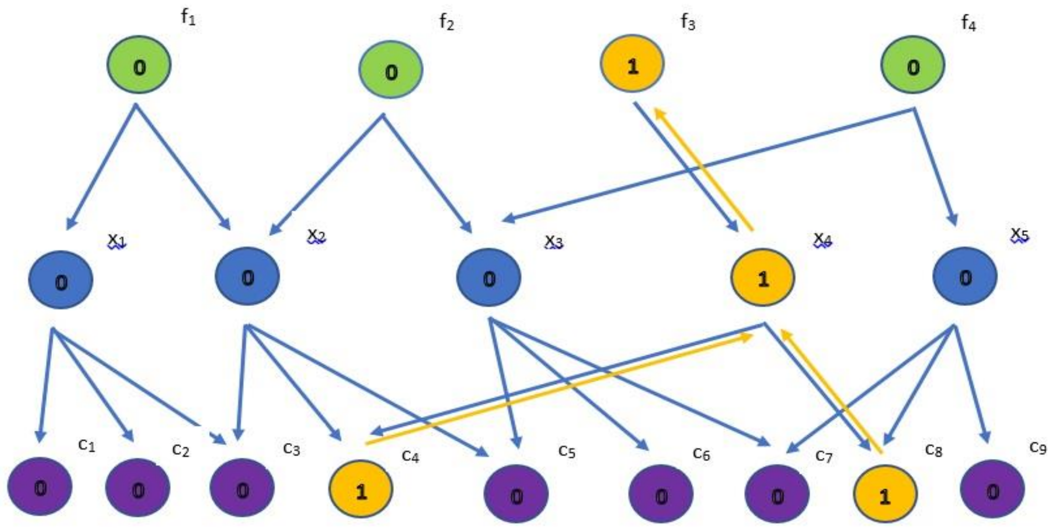

Fig. 4. The graph solution - the anti-causal route

5. Conclusions

The paper proposes a new approach to improve the management of activities for supply-customer services, as an alternative to the existing results in the literature based on the theory of causal graphs. A graph model is generated as a network comprising the main actors: suppliers and consumers, distributed in nodes and respectively the existing interdependence connections between nodes. The causal network is dimensioned according to the supply resources, the production capacity, the transport capacity and the sales capacity.

The management of the supply-customer mechanism is ensured by introducing a causal operator, which allows solving the graph, by locating the suppliers that must meet the requirements of consumers and choosing the optimal supply route. The graph solution is obtained with a minimum effort of calculation and programming, with the help of the causal operator working on a matrix-vectorial representation associated with the service delivery system.

The theoretical results are validated in the simulation and are to be transferred to a software product, made available to the user. The performance of the proposed solution is visible on large structures of the supply-customer networks from various fields of activity, both industrial and economic.

As a perspective, we want to introduce optimality criteria associated with the configuration of the graph, expressed in terms of the distance covered from suppliers to customers, which must be minimized, or in terms of transport costs, which must also be minimized.

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