Generalized Net Model for Outpatient Care in Bulgaria

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Abstract

In the Bulgarian health care system patients are transferred between different health care units within the health care facility, and occasionally between units that are far apart, depending on the stage of the patient's treatment progress. Determining patient resource consumption prior to utilization is vital for the management and planning of health care resources. In this paper we propose a generalized net model of patient flows that can be used to evaluate the current design (or alternative designs) in order to improve the management of the diagnostic consultative centres.

1. Introduction

The provision and planning of health care (HC) systems resources has always been a matter of great importance. Determining patient resource consumption prior to utilisation is vital to HC systems in order to improve planning and management. Common practice for planning and managing hospital capacities is by using simple deterministic approaches to describe the process of HC delivery, i.e. the average needs, the average cost, the average duration of activities, the average patient length of stay (LOS) and the number of discharges etc.[1]. Ideally HC processes or practices and patient management should be coordinated together with HC resources in a more effective manner. Almost always patients need more than one medical investigation. Sometimes the needed apparatuses or services are far away from each other, in different buildings or even in different towns. Various attempts to improve the planning and utilisation of resources within HC systems have been made using statistical and mathematical methods such as Markov models, Phase-type distributions, simulation and compartmental models [2] and Petri nets [3].

In this paper the aim is to describe the development of a generalized net model [4] that describes the flow of patients within part of the Bulgarian HC system in order to optimise the use of resources and model the relationship between several HC units. The rest of this paper is organised as follows. In the next section a brief introduction to the Bulgarian HC system is given. Section 3 introduces the basic concepts of generalized nets (GN). In section 4 the GN model is discussed and finally section 5 concludes this paper.

2. The Bulgarian health care system

Every year a National Framework Contract (NFC) is signed between the National Health Insurance Fund (NHIF) and The Bulgarian Medical Doctors' Union and The Union of Dentists in Bulgaria [5]. The NFC guarantees the right of the health insured persons in accordance with operative Bulgarian laws, i.e. all citizens have equal rights of access to medical care within the framework of the package of medical services guaranteed by the NHIF. NHIF concludes a contract with a medical care unit, if it has the necessary medical and technical equipments.

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Specialised outpatient care (SOC) is an important aspect of the health service in Bulgaria. It is offered mainly in HC institutions that have any of the following units: group practice, diagnostic consultative centre (DCC), medical centre (MC), dental centre (DC) and medical diagnostic laboratories. The SOC includes diagnostic and treatment, accident and emergency, rehabilitation and consultative care.

NFC regulates terms and rules for render of SOC. Specialised outpatient care is provided to health insured persons that have a referral medical card for consultation or joint treatment, or high-specialised medical activities, or hospital admission. Each referral card can be used within 30 calendar days from the date of its grant. After a high-specialised medical assessment by a specialist, the patient has to return back to his/her GP with the filled in referral medical card by the specialist and ambulatory papers for the assessment results.

3. The concepts of generalized nets

Generalized Nets (GNs) are extensions of the Petri nets [6] and other modifications of them. They are tools intended for detailed modelling of parallel processes.

A generalized net is a collection of transitions, defined in turn as a set of places (see Figure 1). For each transition there is an index matrix with elements (predicates). Some GN places contain tokens which are dynamic elements entering the net with initial characteristics and may acquire other characteristics during their movement through the net. Tokens proceed from the input to the output places of the transitions if the predicate corresponding to these places is evaluated as *"true"*. Every token has its own identifier and collects its own history that may influence the development of the whole process modelled by the generalized nets. Two time moments are specified for the generalized nets: start up and termination of functioning.

A generalized net may have only a part of its components. In this case it is called a reduced GN. Here we shall give the formal definition of a reduced generalized net without temporal components, place and arc capacities, and token, place and transition priorities. Formally, every transition Z in the reduced generalized net can be described by the following three-tuple :

$$Z= \langle L', L'', r, t', t'' \rangle,$$

where:

(a) L' and L'' are finite, non-empty sets of places (the transition's input and output places, respectively); for the transition these are $L'=\{l'_1, l'_2, \ldots, l'_m\}$ and $L''=\{l''_1, l''_2, \ldots, l''_n\}$;

(b) r is the transition's *condition* determining which tokens will pass (or *transfer)* from the transition's inputs to its outputs; it has the form of an Index Matrix (IM) as in Figure 2:

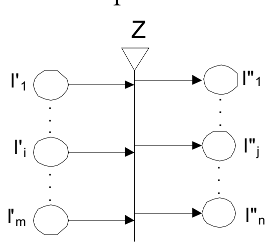

Figure 1: GN transition

$$r = \begin{array}{c|ccccc} & l''_1 & \ldots & l''_j & \ldots & l''_n \\ \hline l'_1 & & & & & \\ \ldots & & & r_{i,j} & & \\ l'_i & & (r_{i,j} & - & predicate) & \\ \ldots & & (1 \le i \le m, & & 1 \le j \le n) & \\ l'_m & & & & & \end{array}$$

Figure 2: Index Matrix

$r_{i,j}$ is the predicate that corresponds to the i_{th} input and j_{th} output place. When its truth value is *"true"*, a token from the i_{th} input place transfers to the j_{th} output place; otherwise, this is not possible.

(c) t' and t'' are the time moments of transition activation and the duration of the transition's active state.

The ordered four-tuple: $E= \langle A, K, X, \Phi \rangle$ is called a *Generalized Net* if:

(a) A is a set of transitions;
(b) K is the set of the GN's tokens;
(c) X is the set of all initial characteristics, which the tokens could obtain on entering the net;
(d) Φ is the characteristic function that assigns new characteristics to every token when it makes the transfer from an input to an output place of a given transition.

4. The GN model

The process for providing a medical treatment to a patient as stated in the NFC, can be described with the help of the GNs. In this paper the activity of specialised outpatient care unit within a diagnostic consultative centre is modelled, as illustrated in Figure 3.

The GN-model consists of five transitions (Z_1, …, Z_5), which represent, respectively, general practitioners, medical institutions for specialised outpatient care, laboratories and centres for specialised analyses, hospital units, and rehabilitation centres. This model is concerned with the movement of patients refereed to here as α-tokens. The arrival of a new patient is represented by entrance of an α-token in place l. When transition Z_1 is activated one or more general practitioners (GPs) refereed to here as β-tokens pass simultaneously to respective output places $d_1,\ldots,d_m$ for the transition, i.e. a GP is activated to treat a patient. After a patient is being seen by a GP, the α-token passes to one of the other output places l_1, l_2, l_3, and l_4 of transition Z_1, representing patient's direction to: a specialist, additional analyses at laboratory, hospital institution or home. When a consultation with a specialist (s_1, …, s_n) is needed, α-token moves into place l_1; a consultant (a γ-token) is activated from a place s_i, depending on the medical centre for SOC. After consultation, the patient will be discharged through place l_8, otherwise the patient will be referred to another unit through the output of the transition, i.e. places l_5, l_6, l_7. The α-token moves toward: transition Z_3 through place l_5, when additional laboratory analyses are required or transition Z_4 through place l_5 when hospitalisation is needed, or transition Z_5 through place l_7 for rehabilitation treatment.

Transition Z_1 represents the process of treatment of a patient by a particular general practitioner and has the following form:

$$Z_1 = <\{l, d_1, \ldots, d_m, l_9\}, \{d_1, \ldots, d_m, l_1, l_2, l_3, l_4\},$$

	d_1	…	d_m	l_1	l_2	l_3	l_4
l	W_{l_d1}	…	W_{l_dm}	false	False	false	False
d_1	false	…	false	W_{d1_l1}	W_{d1_l2}	W_{d1_l3}	W_{d1_l4}
…	…	…	…	…	…	…	…
d_m	false	…	false	W_{dm_l1}	W_{dm_l2}	W_{dm_l3}	W_{dm_l4}
l_9	W_{l9_d1}	…	W_{l9_dm}	false	False	false	false

$, t_1', t_1''>,$

where: W_{l_di} = „the patient needs consultation from the i-th doctor",
W_{dj_l1} = „the patient conditions dictates a consultation from a specialist",
W_{dj_l2} = „diagnose requires additional analyses",
W_{dj_l3} = „the patient needs hospitalization",
W_{dj_l4} = „the therapy given to the patient allows treatment at home",
W_{l9_dx} = „patient revisiting a GP with results of examinations and tests made",
where: $1 \leq i \leq m$ and $1 \leq j \leq m$.

The α-tokens enter place l with initial characteristics such as personal data, medical history. By passing to any of the places d_1, …, d_m, the token collects data, regarding GP examinations, diagnosis and treatment. In the GN-model it is possible to set capacities for places d_1, …, d_m, and it is also possible to regulate the service time and/or arrival time of a patient. The characteristic in place l_1 is: „the patient needs health consultation from a specialist". The GP

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issues referral medical card to the patient for consultation with an appropriate specialist. However, the patient can choose the medical institution for SOC and also the specialist. The consultation can be performed in every district of the country. The referral card lists the examinations that are carried so far as well as the general practitioner conclusions. In place l_2 the tokens obtain as a characteristic "the patient needs additional tests in laboratory or with specialised apparatuses". In place l_3 the tokens obtain as a characteristic: „the patient needs treatment in a specialised hospital institution". Once again the patient can choose the medical institution. In place l_4 the tokens receive as a characteristic: "diagnosis is given and a treatment is completed".

Transition Z_2 represents the process of patient treatment by a specialist for SOC and has the following form:

$Z_2 = <\{l_1, s_1, \ldots, s_n, l_{10}\}, \{ s_1, \ldots, s_n, l_5, l_6, l_7, l_8\},$

	s_1	…	s_n	l_5	l_6	l_7	L_8
l_1	W_{l1_s1}	…	W_{l1_sn}	false	false	false	false
s_1	false	…	W_{s1_sn}	W_{s1_l5}	W_{s1_l6}	W_{s1_l7}	W_{s1_l8}
…	…	…	…	…	…	…	...
s_n	W_{sn_s1}	…	false	W_{sn_l5}	W_{sn_l6}	W_{sn_l7}	W_{sn_l8}
l_{10}	W_{l10_s1}	…	W_{l10_sn}	false	false	false	false

$, t_2', t_2''>,$

where: $W_{l1\_si} = W_{sj\_si}$ = „patient requires a consultation from the ith specialist",

W_{sj_l5} = „ diagnosis requires additional analyses",

W_{sj_l6} = „patient needs treatment in a hospital institution",

W_{sj_l7} = „patient needs treatment in a rehabilitation unit",

W_{sj_l8} = „patient can be treated at home",

W_{l10_si} = „patient with results of the examinations made",

where: $1 \leq i \leq n$, $1 \leq j \leq n$ and $i \neq j$.

The α-tokens enter place l_1 with the initial characteristics and the extra results from analyses, conclusions of the general practitioner, information for chosen specialist and so on. By passing to any of places $s_1, \ldots, s_n$ the token collects data from the specialist examinations regarding diagnosis, treatment prescribed and decisions taken. If a new consultation with another specialist is needed the patient will receive a referral medical card for that. In the GN-model it is depicted by a cycle for places $s_1, \ldots, s_n$. In cases when further information is needed to prescribe a treatment, the patient is sent for additional examinations, which is shown by an α-token passing to place l_5. The characteristic that token obtains in place l_5 is: "the patient needs additional analyses in laboratory or with specialised apparatuses ($u_1, \ldots, u_p$)". Specialists can send patients for high-specialised and expensive examinations. The characteristic of a token in place l_6 is: "the patient needs treatment in a specialised inpatient unit". And in place l_7 the obtained characteristic is: "the patient needs rehabilitation treatment". The α-token enters place l_8 to indicate that a patient can be treated at home.

Transition Z_3 represents the process of performing medical tests:

$Z_3 = <\{ l_2, l_5, u_1, \ldots, u_p, l_{13}\}, \{ u_1, \ldots, u_p, u_{p+1}, \ldots, u_v, l_9, l_{10}, l_{11}\},$

	u_1	…	u_p	l_9	l_{10}	l_{11}
l_2	W_{l2_u1}	…	W_{l2_up}	false	false	False
l_5	W_{l5_u1}	…	W_{l5_up}	false	false	False
u_1	false	…	W_{u1_up}	W_{u1_l9}	W_{u1_l10}	W_{u1_l11}
…	…	…	…	…	…	…
u_p	W_{up_u1}	…	false	W_{up_l9}	W_{up_l10}	W_{up_l11}
l_{13}	W_{l13_u1}	…	W_{l13_up}	false	False	false

$,t_3', t_3''>,$

where:

W_{li_uj} = „the j-th examination of the patient is needed",

$W_{ux\_uy} = W_{li\_uy}$,

W_{ui_lk} = „tests are completed and results have to be sent back to: a general practitioner, a specialist, an inpatient healthcare unit",

where: $i \in \{2, 5, 13\}$, $1 \le j \le p$, $1 \le x \le p$, $1 \le y \le p$, $k \in \{9, 10, 11\}$ and $x \ne y$.

In places l_2, l_5 and l_{13} α-tokens obtain the same characteristics: "needs for examinations or tests". These patients are refereed from GPs, specialists, or healthcare units respectively. In places $u_1, \ldots, u_p$ tokens obtain characteristics: "the j-th laboratory examination or examination with specific apparatuses is completed". The tokens characteristics in places l_9, l_{10} and l_{11} are: "test results are completed", and send back to GPs, specialists or inpatient healthcare units respectively.

Transition Z_4 represents the process of patient admission to a specialised hospital unit:

Z_4 = <{ $l_3, l_6, l_{11}, h_1, \ldots, h_k$}, { $h_1, \ldots, h_k, l_{12}, l_{13}$},

	h_1	…	h_k	l_{12}	l_{13}
l_3	W_{l3_h1}	…	W_{l3_hk}	false	false
l_6	W_{l6_h1}	…	W_{l6_hk}	false	false
l_{11}	W_{l11_h1}	…	W_{l11_hk}	false	false
h_1	false	…	W_{h1_hk}	W_{h1_l12}	W_{h1_l13}
…	…	…	…	…	…
h_k	W_{hk_h1}	…	false	W_{hk_l12}	W_{hk_l13}

,t_4', t_4">,

where:

W_{li_hj} = „patient need to be hospitalised in the j-th unit for inpatient medical care",

$W_{hx\_hy} = W_{li\_hy}$,

W_{hi_l12} = „ additional examinations are needed",

W_{hi_l13} = „patient is to be discharged from the hospital unit",

where: $i \in \{3, 6, 11\}$, $1 \le j \le k$, $1 \le x \le k$, $1 \le y \le k$ and $x \ne y$.

The characteristics of places $h_1,\ldots,h_k$ are: "patient admitted for a treatment in the j-th inpatient healthcare unit". In place l_{13} tokens obtain as a characteristic: "discharge of the patient".

Transition Z_5 represents the process of patient admission to a medical clinic for rehabilitation:

Z_5 = <{$l_7, r_1, \ldots, r_q$}, { $r_1, \ldots, r_q, l_{14}$},

	r_1	…	r_q	l_{14}
l_7	W_{l7_r1}	…	W_{l7_rq}	false
r_1	false	…	W_{r1_rq}	W_{r1_l14}
…	…	…	…	…
r_q	W_{rq_r1}	…	false	W_{rq_l14}

,t_5', t_5">,

where: W_{l7_rj} = „ patient needs to be hospitalised in the j-th rehabilitation unit",

$W_{rx\_ry} = W_{l7\_hy}$,

W_{rj_l14} = „discharge of the patient",

where: $1 \le j \le q$, $1 \le x \le q$, $1 \le y \le q$ and $x \ne y$.

The characteristics the tokens obtained in places $r_1, \ldots, r_q$ are: "patient admitted for a treatment in the j-th rehabilitation unit" and in place l_{14} tokens obtain as a characteristic: "patient is discharged".

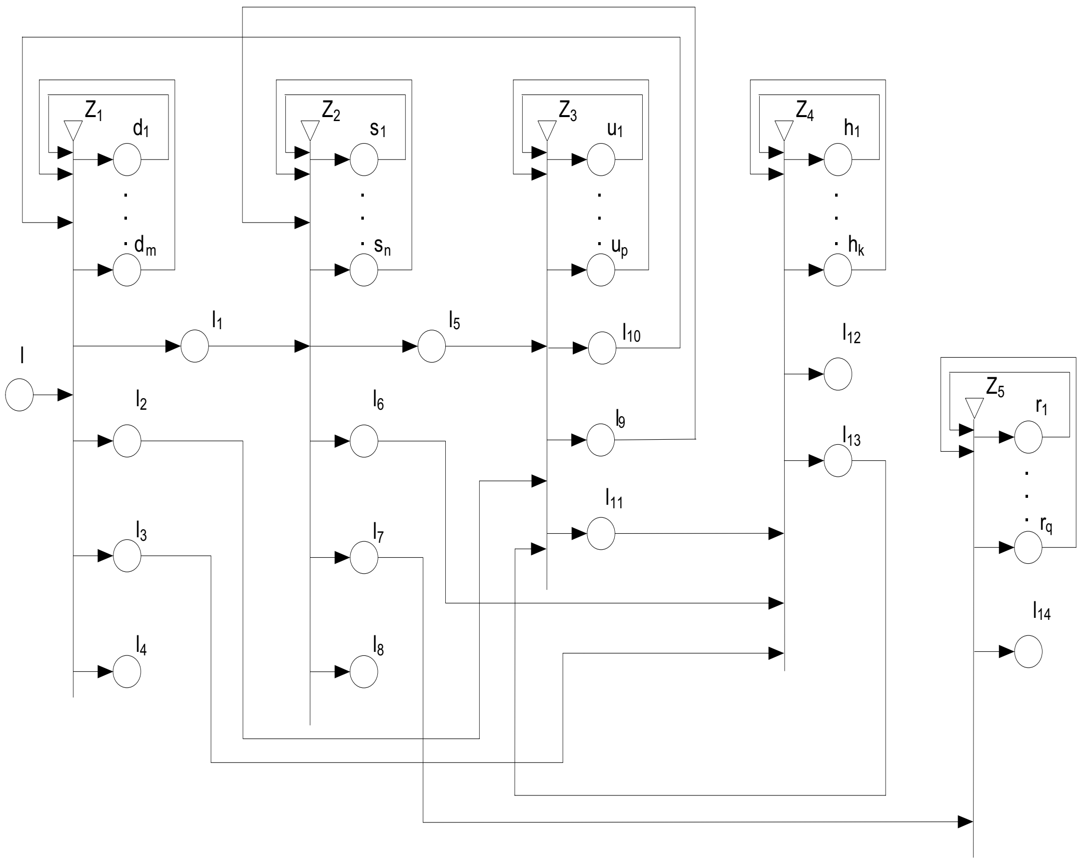

Figure 3. GN simulation model

5. Conclusion

The proposed GN model of patient flows can be used to evaluate the current design (or alternative designs) in order to improve the management of the diagnostic consultative centres (DCC), to reduce waiting times, queuing and blockage. The modelling formalism is particularly suited to the problem since it allows the dynamics of the system to be sensitive to different instantiations of system variables such as processing time. Also information processes can be easily captured by GN tokens, their characteristics and transition condition predicates. The GN model can be implemented using simulation software and data from the DCC, which is the subject of further work.

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