EMERGENCY DEPARTMENT:
A GENERAL ADAPTABLE SIMULATION MODEL IMPLEMENTED IN ARENA

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Abstract- The Emergency Department of a hospital is devoted to provide first aid to outpatients. A correct organization and resource dimensioning is very important both in the planning and in the management phase and may be usefully supported by a simulation model to be applied by administrators and operators. As an emergency department is a very complex framework, a model which simulates it requires a large amount of time and an expert software programmer to be built and implemented. In this paper a generalized flexible model has been built up, able to reproduce all common structural and functional characteristics of every actual emergency room. This simulation model can be easily adapted to almost all emergency departments only by defining its functional parameters without altering its structure; it is written in language SIMAN by tool Arena, widely diffused, and permits an easy readability also by non expert users.

Keywords- Emergency department, parametric model, discrete simulation.

1 INTRODUCTION

The emergency department is a hospital department devoted to provide first aid to outpatients who suffer from an injury or an illness requiring urgent care.
Emergency department service is characterized by high variability of patient arrivals, depending on time (different intervals of the day, week, year), according to extreme randomness; moreover the required assistance type may vary according to the patient characteristics and to the suffered injury or illness. On the patient side, a response which shall be quick enough (sometimes immediate) with respect to patient state severity, is expected, also in case of congestion.
As a consequence of all above needs, an emergency department shall be correctly designed and managed for what concerns structures, technological resources and human resources, in order to supply a high quality service at minimum cost.
Once given the presence of randomness in patient arrival, in patient management (due to priorities and possible preemption) and in services' duration, an analytical model (see [16]) is not suitable, as it is able to provide only mean behaviour results, while a simulation model, able to describe in detail system behaviour, and to give results related to extreme conditions, appears to be the most convenient, as shown by a wide literature. Many papers using simulation are dedicated to a generic emergency department to solve specific management problem (see [4], [11], [9], [26], [18], [31], [33], [17], [20], [32], [12]) or to study the effects of triage organization (see [7]); paper [25] studies the behaviour of a generic emergency department in the case of a maxi-emergency; the above papers are addressed to analyze generic departments to solve specific problems. Other papers solve problems of the same kind but applied to specific departments (see [23], [30], [3], [10]); in particular [10] implements the model in simulation tool Arena, which is particularly friendly and understandable also by non experts. In some papers the simulation model describes also (or only) other services connected with the emergency departments, like ambulances and patient transportation, either in a generic situation (see [19], [27], [5], [1], [21], [3]) or in a specific one ([28], [15], [6]); paper [21] studies interaction among emergency department and other services or departments inside and outside the hospital. Paper [13] suggest a generalized model of emergency department without discussing its implementation. A side consideration is due to papers dedicated to triage ([2], [8], [14], [22], [24]).
In the present paper a generalized model of emergency department, flexible and adaptable to the majority of existing departments, is presented; its adaptability permits to model and simulate both departments managing ambulances with doctors and/or nurses and departments independent from patients' transportation systems; patients' arrivals probability distributions, both in normal and in exceptional conditions, are characterized by adjustable parameters; structural and human resources management, turns of duty and priority rules can be ruled so to reproduce the behaviour of the studied service (see figure 1 for general flow chart model). The model implementation is developed by tool Arena, widely used in the world and very easy to be understood by non expert users, like medical personnel, with whom the model shall be adapted and employed to adjust department dimensions and to improve department effectiveness and efficiency.
For what concerns the paper organization, the department operation and the generalized model is discussed in Section 2 while its implementation in Arena is explained in Section 3; results and possible suggestions are reported in Section 4. Conclusion follows in Section 5.

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2. EMERGENCY DEPARTMENT OPERATION AND GENERALIZED MODEL

If we consider the emergency department from the patients' point of view, we may see that their movements may be outlined as follows:
- arrival;
- triage (after possible wait in queue);
- a sequence of medical examinations (with possible intervention and possible resuscitation), and exams or specialized consulting, alternatively followed by: sending home, hospital admission, short term admission; often examinations require wait in queue; sometimes the sequence may be interrupted by patient's death in severe cases;
- a final examination, followed either by sending home or by hospital admission, at the end of short term admission, if occurred.

The presented model may be considered to be absolutely general and it summarizes all application experience of last years (11 specific departments in Italy and abroad, in normal and exceptional situations), as the above actions' sequence (triage, different examinations and exams) is widely adopted in all emergency departments. The setting of all parameters ruling all phases' durations however permits to activate or deactivate single phases in correspondence of specific applications.
The general sequence of arrival, triage and examinations is represented in figure 1. The required resources are:
- structural resources: major and minor treatment rooms, waiting rooms, short term admission rooms;
- technological resources: specific instruments, which are generally strongly connected with the structural resources, and therefore are not considered separately;
- human resources: medical doctors, general and specialist nurses, auxiliary operators, working according to well defined rules and turns of duty.

Resources employed to perform single tasks are chosen from available resource sets, according to predefined rules stating priority, compatibility and suitability.
Starting from this very general model with low detail, every function will be explained in detail.

2.1 Patients arrivals
We may classify arrivals as normal arrivals, special arrivals and pseudo-arrivals.
Normal arrivals are related with either traumatic accidents or urgent medical need, due for instance to infarct, stroke or severe health worsening; their happening is absolutely random and independent, even if a strong dependency on time (day's intervals and weekdays) and on patient type (as will be specified later) is present in the mean. Normal patients may arrive by their own means (on foot, by car) or by an ambulance, which may be provided either by the same department (equipped or not with a doctor or a nurse) or by a separate rescue organization.

Special arrivals are related with exceptional situations which cause abnormal increase in patient arrivals for a limited time period, and may be divided in two groups.

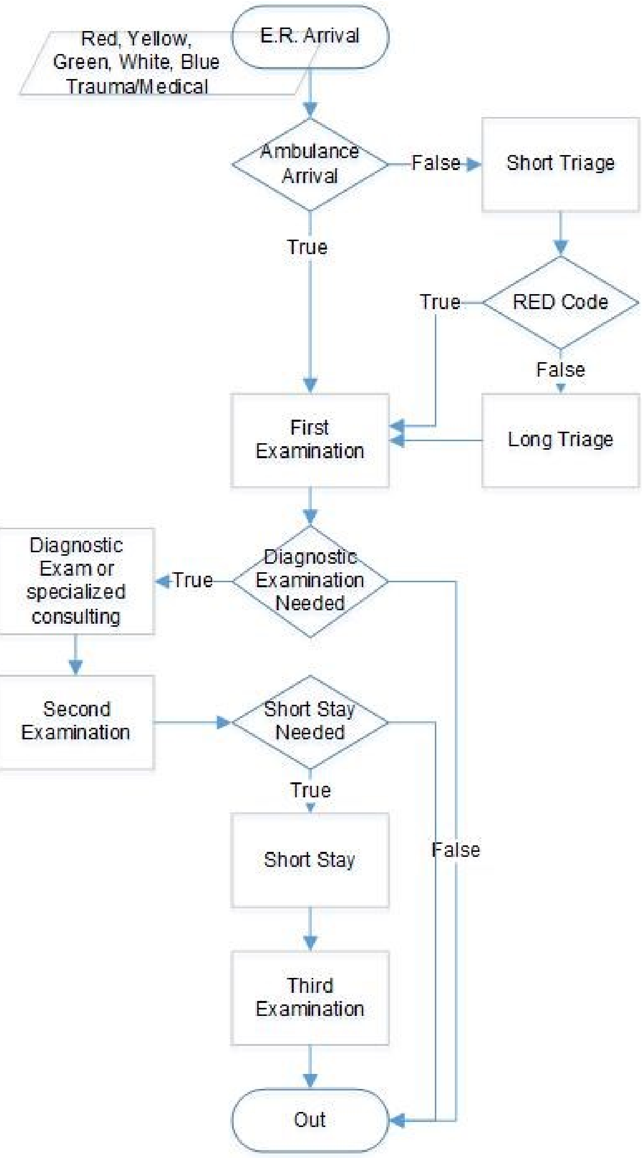

Figure 1: Generalized flowchart diagram

In the first group we classify patients generated either by extraordinary weather (high temperature, dryness, high humidity, low temperature) or by epidemics (typically flu) who generally are either old or already weakened by other illness; their arrivals are random but depend on time according to the specific cause. In the second group we classify patients generated by a maxi-emergency, which happens for instance because of severe road accidents involving many vehicles, fires, building collapses, earthquakes, spread of toxic gas, etc.; such patients may be in a large number (from tens to hundreds) and arrive in a very short interval (from an hour to six hours), and therefore they evidence a brutal, even if temporary, insufficiency of immediately available rescue with respect to assistance requests, to which the department shall react with a rapid pre-ordered outstanding effort; the maxi-emergency occurrence is rare and random, the patients' generation has been classified, according to the cause, as minimal (48 patients of various types in an hour), strong flow-short term (100 patients of various types in an hour) or long term (272 patients of various types in 6 hours) .

Pseudo-arrivals are assistance requests by people admitted in the short term admission rooms; such rooms are dedicated to short stays and are managed by the same emergency department doctors' and nurses' team; the assistance request are random independent but their mean is proportional to the number of currently admitted patients.

The mean arrival time depends on the type of patient and is generally obtained by a suitable statistical investigation.

2.2 Triage

All arriving patients are immediately selected by the same unique filter (triage), which is ruled by specialized nurses. The selection is based on the presented life parameters, predefined and universal, breathing, heartbeat and consciousness, which determine the immediate life danger.

The selection assigns a colour code, according to immediate life danger, and related urgency:

- red code, aid shall be immediate, as any wait may cause death;
- yellow code, aid shall not be delayed more than some minutes, wait may increase severity, a frequent check is required if assistance cannot be immediate;
- green code, aid may be delayed, a limited wait (tenth of minutes to two hours) is permitted without danger; anyway assistance cannot be supplied out of the hospital;
- white code, no urgency and no danger, any wait cannot cause damage; assistance should be supplied out of the emergency department (general practitioner or hospital ambulatory).

Beside the upper colour codes, there is the blue code, which is assigned to patients who received assistance by the emergency department in previous days and return for checks (for instance for stitches on a wound).

The triage operation is executed in two phases:

- a first look, which requires a very short time, e.g. one minute, only to reveal a possible red code, and in such a case assistance is immediate; if all rooms, doctors and nurses are busy with lower code patients, pre-emption takes place, i.e., other actions are interrupted to assist the red code patient; the first look is executed by the ambulance personnel, if the patient arrives by ambulance;
- a second look, where the patient (of yellow, green or white code) gets measurements (temperature, blood pressure, electrocardiogram if necessary, …), first simple assistance (e.g., bandage) when necessary, and the nurse collects patient's personal data and information about his/her injury or illness. After second look triage the patient is put in a waiting queue and remains in a waiting room under the supervision of triage nurse(s); the complete assistance will be obtained according to colour priority (yellow, green, blue, white) as soon as a suitable room and a suitable doctor-nurse team is idle. During the waiting period a health worsening is possible: in such a case the triage nurse(s) shall upgrade the code and proceed accordingly.

Blue code patients do not get triage and are directly put in a waiting queue with priority on white code patients.

2.3 Examination sequence

Patients of red code are assisted by following a fixed examination sequence:

- possible pick up by the department ambulance, equipped with a department doctor or a nurse according to department rules, if the department manages ambulances;
- first look triage, possibly in ambulance;
- first examination, obtained immediately, also by pre-emption with respect to lower code patients being assisted when no assisting personnel is idle; by such examination possible resuscitation, stabilization and assistance are provided; a major treatment room and a suitable doctor-nurse(s) group is required, according to the department rules; major assisting rooms may be either generic for red codes or specifically devoted to traumatic or medical assistance, according to department logistics; at the end the assisting doctor(s) alternatively decide(s) about: a) return home, b) hospital admission, c) short term room admission, d) further exams or consultations; patient's death may interrupt the examination;
- possible exams or consultations to investigate the patient's clinical picture; exams may be effected either inside the department (e.g. urine or blood tests) or in a laboratory; consultations are generally obtained by calling a hospital specialist (e.g. a cardiologist or a neurologist);
- second examination after exams' or consultation results, after which the assisting doctor(s) alternatively decide(s) about: a) return home, b) hospital admission, c) short term room admission; patient's death may interrupt the examination;
- third examination after short stay; it is to be specified that admission in short term room is chosen whenever a quick evolution of the clinical state is expected, so to decide for either home or hospital; short stay is limited to a maximum of 36-48 hours, but is generally shorter.

Patients of yellow code are assisted by following a different examination sequence:

- possible pick up by the department ambulance, equipped with a department doctor or a nurse according to department rules, if the department manages ambulances;
- first look triage, possibly in ambulance;
- second look triage and wait in the waiting room;
- first examination, obtained with priority with respect to lower code patients; by such examination stabilization and assistance are provided; a major treatment room and a suitable doctor-nurse(s) group is required, according to the department rules; major assisting rooms may be either generic for yellow (sometimes for both red and yellow) codes or specifically devoted to traumatic or medical

assistance, according to department logistics; at the end the assisting doctor(s) alternatively decide(s) about: a) return home, b) hospital admission, c) short term room admission, d) further exams or consultations; patient's death may interrupt the examination;
- possible exams or consultations to investigate the patient's clinical picture; exams may be effected either inside the department (e.g. urine or blood tests) or in a laboratory; consultations are generally obtained by calling a hospital specialist (e.g. a cardiologist or a neurologist);
- second examination after exams' or consultation results, after which the assisting doctor(s) alternatively decide(s) about: a) return home, b) hospital admission, c) short term room admission; patient's death may interrupt the examination;
- third examination after short stay.

Patients of green and white codes are assisted by a sequence which differs from the one of yellow codes in the choice of the room, which may be either a major treatment or a minor treatment one, and sometimes may be in common with rooms devoted to yellow codes; because of lower urgency, consultations are obtained in specialized departments of the hospital by moving the patient instead of calling a specialist; an obvious difference lays in the assistance priority, so that the queue time may be longer for green codes and much longer for white codes; finally, patient's death is very rare.
Patients of blue code get only one short visit.
During assistance sequence a change of patients severity (change of colour) may occur; in such a case the operations related to the new colour are applied.
The duration of various examinations depend on: 1) patient colour, 2) traumatic or medical assistance required, 3) composition of assisting team, 4) examination order (first, second, third); the most suitable statistical time distribution is a gamma one.

2.4 Employed resources

Emergency department organization always subdivides rooms into colour areas: a red area, devoted to red codes; a yellow area for yellow codes; a green area for green codes and a blue-white area for blue and white codes. In case of reduced department operations amount, some areas may be grouped together, for instance red area, green-yellow area and blue white area; for large operations amount, each area may be further subdivided into rooms devoted to traumatic and medical assistance. Room arrangement may change during the day, for instance some rooms may be closed and other rooms grouped together during the night. New rooms may be opened in case of a special patients arrival or a maxi-emergency, according to a pre-ordered plan.
For what concerns doctors' and nurses' staff, every person has his/her turns of duty, during which he/she is devoted to a specified area; rules are pre-defined for possible changes of area, whenever necessary (for instance from yellow to red area). Auxiliary people are dedicated to patients movements. In case of special arrivals or maxi-emergency, "available" doctors and nurses are called (according to a pre-ordered procedure) and arrive in a short time (typically, half an hour) to increase the number of present ones.

3 SIMULATION MODEL IMPLEMENTATION IN ARENA

For the above model implementation Arena simulation tool was chosen, by considering that it is widely used in the world, and is easily read also by non users, due to animation and clarity of graphical representation.
The developed model uses about 250 blocks, of which about 40 creation blocks, about 100 process blocks, about 100 assign blocks and about 60 decide blocks; the model employs about 5 sub-models; obviously the small amount of different blocks increases readability.
The model may be split into three parts.
In the first part patient arrivals and pseudo-arrivals are generated.
In order to obtain the maximum model flexibility we chose to implement a different input for every possible patient type, and define for the corresponding arrivals a specific (either random or deterministic) scheduling. If a patient type is not to be considered, then the corresponding scheduler is set to zero.

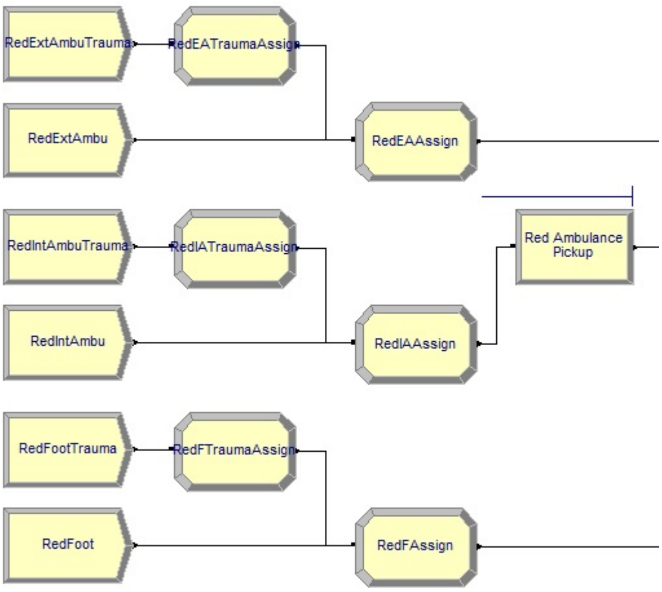

Figure 2: Red Code arrivals full schema

A set of creation blocks generate all types of normal patient arrivals, more precisely red, yellow, green and white codes, each one in all possible versions, i.e., arrival by department ambulance, by external ambulance and by foot, i.e., individual transportation means; blue codes arrive only by foot; all generations are modulated by a different scheduler, which permits to obtain random independent arrivals whose inter-arrival time may vary during the days of a week. To every patient a first vector, reporting colour, priority and next step is assigned. Patients arriving by department ambulance may employ a doctor or a nurse for the rescue trip, according

to a “preferred order” which is defined by the department rules. Obviously not all patient types shall be activated: for instance if the considered department does not manage ambulances, then all codes arriving by inner ambulance are not created by setting the related schedulers to zero.
Arrivals are divided by colour classification **Code** (Red, Yellow, Green, White, Blue), **type** (traumatic or medical patients) and E.R. **arrival mode** (internal or external ambulance, autonomous) (see figure 2 for the detail of Red Code Arrivals)**;** such a complex distribution of arrivals, although it is not applicable to E.R. with an easier management of patients and to whose that do not have their own ambulances, allows better and more accurate resource management.
The first Create Block rules the arrival of the patients associated with a specific schedule (see figure 3) that represents the number of arrivals expected by color, type and arrival way.

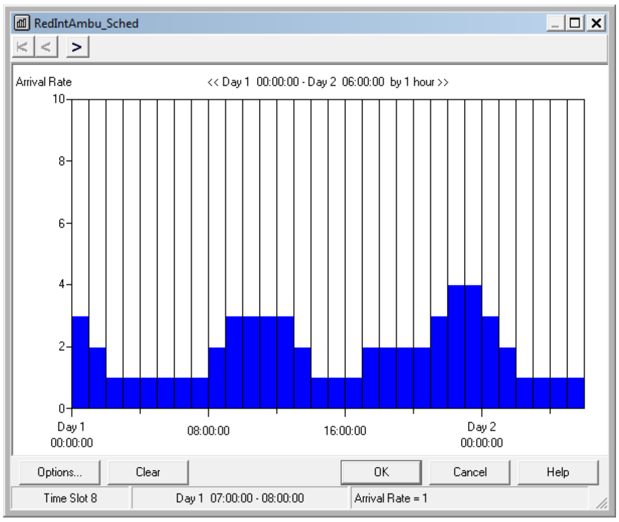

Figure 3: arrival schedule representation

The Assign Block assigns to each entity some attributes (as may be seen in the following list) which will address entities in the right way.

Attribute	PatientCode	"Red"
Attribute	PatientPriority	RedPriority
Attribute	Ambulance	1
Attribute	IntAmbu	1
Attribute	PatientPathState	"3FirstVisit"
Entity Picture	Picture.Red Ball	1
Attribute	AccompanimentNeeded	%RedAccompaniment

“Ambulance Pickup” Process (see figure 2) Seizes and Releases the resource that is needed in case an Internal Ambulance is sent to pick-up the patient.

A different creation block generates special arrivals (see figure 4), scheduled on a year time interval; every special arrival in its whole both generates single patients, who are addressed to increase the respective normal patients, and causes a suitable call for new available doctors nurses and rooms, whose amount is proportional to the number of special patients arrived.

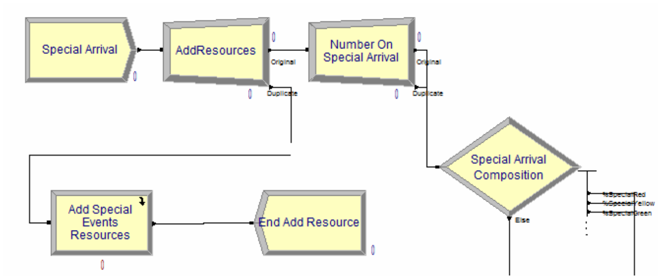

Figure 4: special arrivals block schema

Arrivals are scheduled on an annual basis and then a separate module and a following “N-Way by chance” decision module split the arrivals simulating (in a parametric way) the arrival of a certain number of patiens with different color code distribution.

“Add Special Event Resources” Submodel is needed to introduce in the simulation additional resources (Doctors, Nurses, Rooms/Beds) for a limited period or untill there is at least one special entity in the model. This settings are parametrical decided by a group of variables (see figure 5).

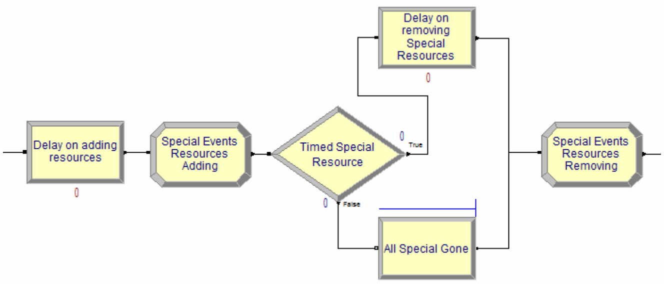

Figure 5: special resources adding submodel detail

Finally pseudo arrivals are generated by a creation block where the mean is modulated by a decide block, in order to be proportional to the number of occupied beds in the short term room (see figure 6).

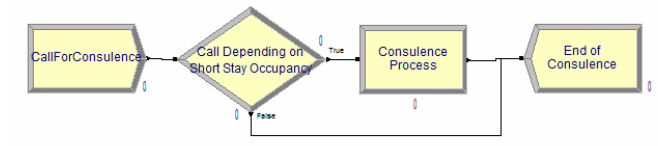

Figure 6: pseudo arrivals model

Pseudo Arrivals are scheduled on a day period, using the parameter ResUtil(ShortStayBed)*100 it is possible to discard a number of calls according to the number of short stay bed occupancy.

In the second part triage is reproduced.
Red code patients arrived by ambulance skip the triage, while red codes arrived by individual means limit their us to first look triage. All other codes perform first look and second look triage, but the examination may be interrupted by the arrival of a red code; such an interruption is obtained by building a sub-model where the examination time is fractioned in a number of (parametrically predefined) time units and the examination can be broken in correspondence of a unit end, whenever required, and reset just after the interrupting patient has been served (triage simulation schema is shown in figure 7).
Apart from decision boxes using entity color code attribute to determinate the right path for each entity and assign boxes we have two process:

- short triage, a simple Seize Delay and Release process used to reserve the right resource (triage nurse or any available Nurse choosen with priority from a set)
- a long triage subprocess whose detail is quite similar to the examination process

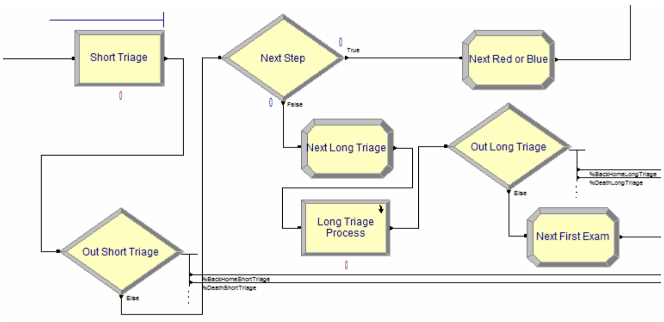

Figure 7: Triage Model

In the third part the assistance sequence is reproduced.
The first and possible second examination seen in the previous paragraph (as shown in figure 8) are simulated by sub-models similar to the one reproducing second look triage, in order to permit pre-emption whenever required; examinations' duration is dependent on patient's characteristics, colour, examination order, traumatic or medical, and ruled by the related parameters. Possible inner/outer exams and consultations, with different parameters according to the patient's characteristics, are represented; required patients' transportations are provided too.

In first exam submodel we can observe these three subsections:

1. a 2 way by chance decision box that determines whether an entity requires an auxiliary person to reach the room where the examination will be made
2. the set of boxes that initialize the cycle which will be repeated for a parametric number (LoopNumber variable) of times, each one with a duration that is assigned in the submodel according to entity tipe and colour code and to a specific gamma duration set by function: *GAMM(betaFirstExam,RedTraumaExamDuration)* that will be divided in duration/ LoopNumber subdurations
3. the cycle that will be repeated for LoopNumber times blocking correct resources

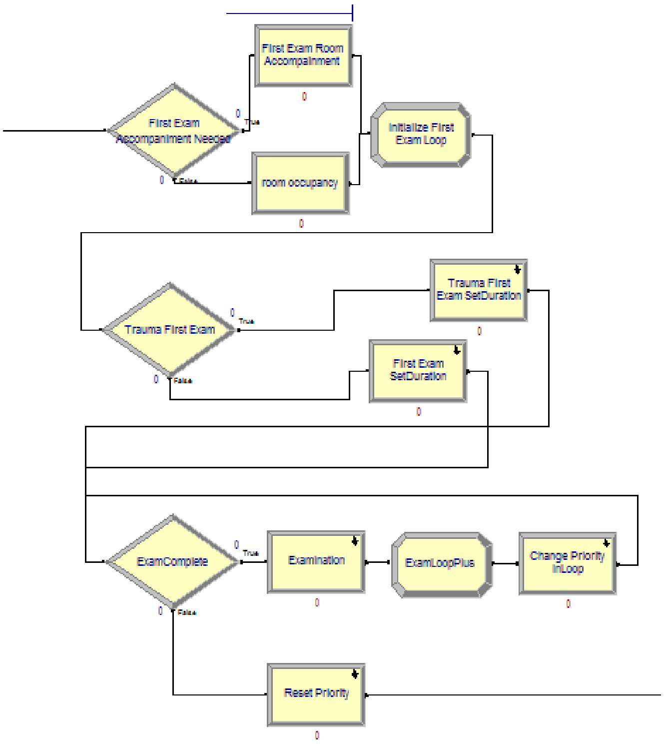

Figure 8: first examination simulation schema

The way used to manage in the right way the priority of the entities during examinations (see figure 9) is ruled by the assignment of particolar values to the attribute *patientpriority* for each entity.
According to entity colour code a particular value (predefinited by a variable) is set at its arrival:

RedPriority	10
YellowPriority	40
GreenPriority	50
WhitePriority	60
BluePriority	46

Remember that at lower priority value corresponds to higher priority. When entity enters in the loop simulating interruptible examination process, its patientpriority value it's lowered, so te process works trying to complete examination already started before beginning a new one.

RedPriorityLoop	5
YellowPriorityLoop	15
GreenPriorityLoop	25
WhitePriorityLoop	35
BluePriorityLoop	24

Note that only red code patients can interrupt other codes loop (other priority values are lower than the smaller priority when the entity is not looping).

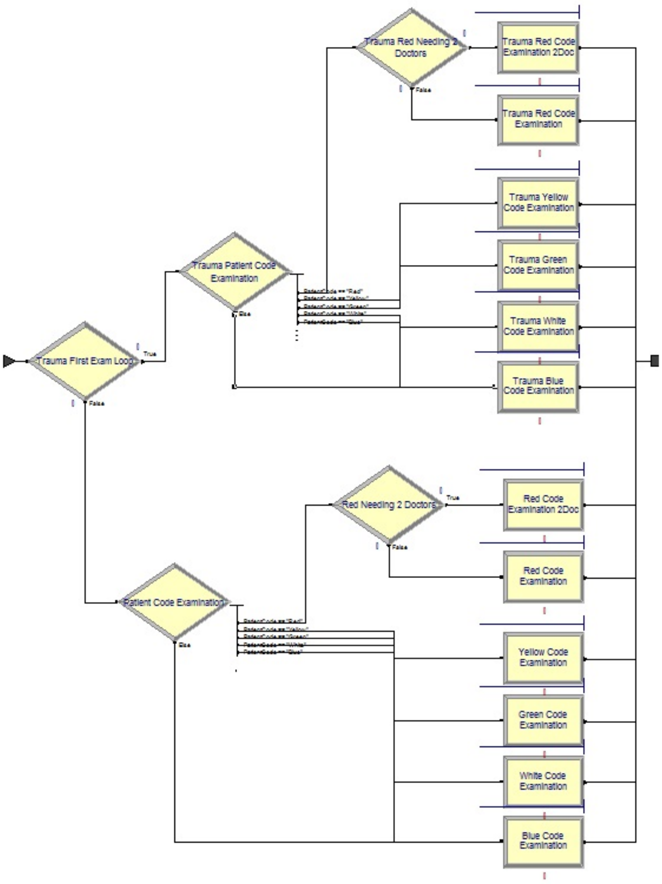

Figure 9: First Examination resources submodel

In the fourth part short term possible admission to the short term room is reproduced by means of a submodel, together with the required third examination.

The employed resources, rooms, doctors, nurses and auxiliary people are listed in separate sets, which report the amount of currently idle elements; such amounts are varied according to duties, time and assistance requests, which are satisfied according to current patient's priority or pre-emption.

Parameters reporting mean and variance of examinations duration are obtained by statistical inference from department data. Priorities are defined according to department operation rules.

4 SIMULATION RESULTS AND THEIR USE TO IMPROVE DEPARTMENT SERVICE QUALITY

4.1 Generalities

Arena model may be run to reproduce a comparatively long interval: one to three years are advised, with a warm-up period of two to four weeks.

The first qualitative result is the animation, which permits an approximate evaluation of queues and of general system behaviour.

From the quantitative point of view, the software permits to know:

- all values of patients' flow for every step;
- waiting times and queue lengths (minimum, average and maximum) both for single patient types and for single examinations;
- total patients' time in the department, separated for single patient types;
- resource utilization.

From the analysis of above results effectiveness and efficiency of the department service can be evaluated.

Only to give some examples:

- from the patients point of view, waiting time for red code first examination shall be zero, waiting time for yellow codes first examination shall be short, total time for green and white codes shall be acceptable, etc.;
- from the operators' point of view, mean busy times and work pikes shall be acceptable, otherwise the performance decreases;
- from the administrators' point of view, the costs shall be bearable.

From the evaluation of department performance useful changes in resources at disposition, turns of duty and working rules can be suggested.

4.2 Adaptation of general model to a specific department

This is obtained without any change of model structure, but only by means of parameter setting.

More precisely we have to set:

- arrival schedulers (possibly some may be set to zero), whose parameters are obtained by past time statistics;
- examinations' duration distributions, whose parameters are obtained by past time statistics;
- resources' schedulers, whose parameters are obtained by department service rules;
- attributes ruling priorities, preemption, and resources' employment, obtained by department service rules.

4.3 Model applications and related results

The model was applied to several different emergency departments; for every application the model was validated by comparison with current true data. From the examination of actual performance, critical aspects were evidenced, and changes in the service management were tested by resetting some of the model parameters; the effects of such changes, in terms of new service performance, were reported to department managers in order to evaluate them and consider possible implementations.

The model was applied to nine emergency departments, more precisely:

- four emergency departments of city hospitals, with workloads between 90,000 and 150,000 patients per year and no ambulance management; two of them were internally divided in two areas for traumatic and medical assistance;

one of them was tested also for the case of maxi-emergencies;
- four emergency departments of small city hospitals, serving a large geographical area including many small urban nuclei, with workloads between 20,000 and 70,000 patients per year and internal ambulance management; one of them was tested also for the case of maxi-emergencies;
- one emergency department of a specialized pediatric hospital with a workload of 20,000 patients per year;
- two urgent assistance centres, able to treat only green and white codes, while red and yellow codes are transfered to a larger neighbour hospital by an ambulance under the assistance of a doctor (for red codes) or of a nurse (for yellow codes);

For all examined departments we found that the assistance to red codes was perfect, while for some of them the waiting time for lower codes was too long, and the workload for medical personnel was very high for some intervals of the day; in such cases a different setting of turns of duty with a light increase of employed personnel was suggested. In one case only an auxiliary person needed to be added to solve patients' transportation problems.

5 CONCLUSION

A generalized, adaptable model of almost all existing emergency department has been built and implemented on the computer by means of an easily readable and usable tool running on personal computers. The model can be adapted to simulate any emergency department after the only parameter setting without requiring structural modifications. Many applications proved model effectiveness.

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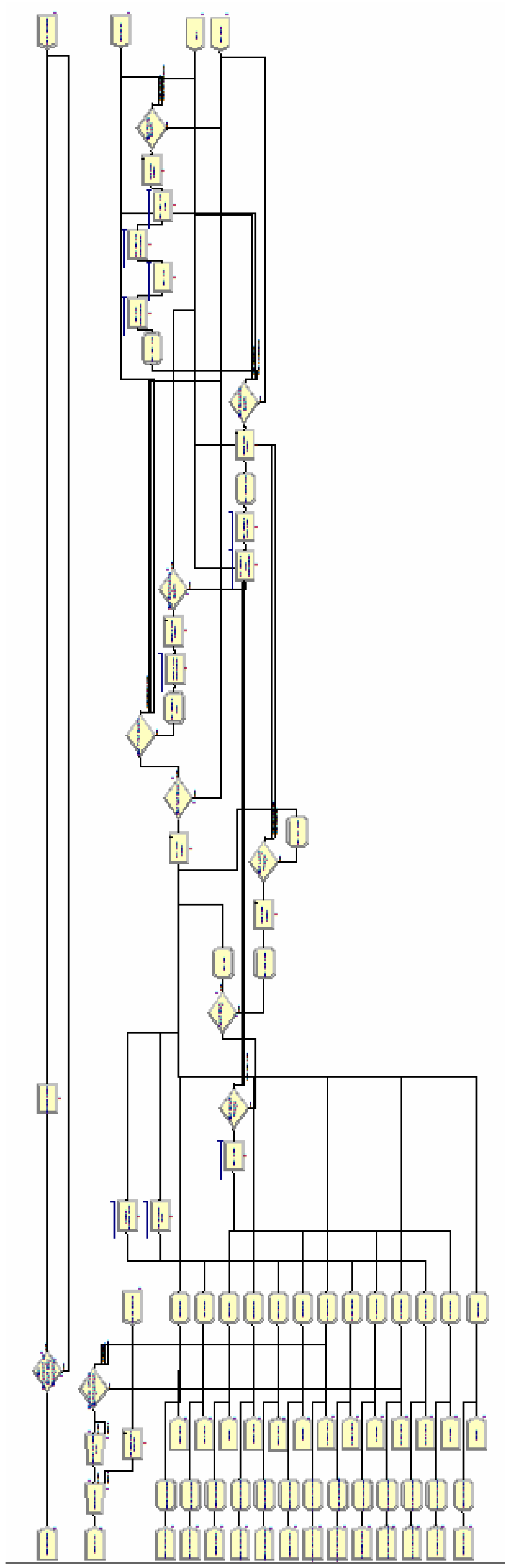

Figure 10: Arena Full simulation model

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