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# PERINATAL ASSISTANCE NETWORK PLANNING VIA SIMULATION


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**Abstract:** *Consider a geographical region where population is distributed in health districts, and there exists a neonatal care network, which includes birth centres able to supply assistance at three levels, respectively basic assistance, mild pathology care and intensive care. Each mother-to-be is admitted to a facility where the assistance level corresponds to the expected newborn conditions; newborn transfers from a lower to a higher-level facility are affected if conditions worsen. Each district has a known probabilistic demand for each care level previously mentioned and each facility is characterized by its capacity, i.e., the amount of patients simultaneously admittable there. A simulation model describing mothers and newborns movements from districts to birth centres and among centres has been built up, with the aim of revealing inadequacies of the assistance network and of obtaining useful suggestions about network resizing to improve service quality and reduce trouble due to distance. The model has been applied to Veneto region in North-East Italy but its use may be extended to other similar situations.*

***Key words***: *perinatal assistance network; decision support; discrete stochastic simulation*

## 1. Introduction

In recent years numerous clinical and technological advances have brought about dramatic improvements in neonatal care, enabling newborns that are severely premature or born in critical conditions to be kept alive. For this small group of newborns few specialized facilities, able to supply neonatal intensive care, are activated to serve large catchment areas. Alongside this restrict group of patients, there is a large group of newborns coming into the world in physiological or mildly pathological conditions, who can be cared for at less specialized facilities and by less expert staff. It is more convenient to distribute such facilities on the territory so to serve smaller catchment areas, and to contain the distances between the facilities and the population residential areas they serve. To satisfy all the above requirements demands the creation of a birth assistance network with facilities of different levels, moreover transfers needed from lower level facilities to higher level facilities for patients whose initial conditions deteriorate shall be provided. Three-tiered perinatal care networks have been planned in Europe and in USA ever since the '80s (Brann et al. 1980; Le Roy et al. 2006; Van Reempts et al. 2007). The three levels correspond to basic neonatal care on the first level, intermediate care for neonatal diseases on the second and neonatal intensive care on the third. Each perinatal care network has to be accurately planned in logistic terms, providing suitably sized and connected facilities for ensuring the maximum efficiency of each level of care.

In this paper we simulate movements of patients from the territory towards the assistance network and inside the network. We assume that mothers-to-be live in health districts dotted all over a given territory; every mother-to-be is admitted to a birth centre serving the level corresponding to the needs of her pregnancy; therefore each district has a certain demand for each of the three perinatal care levels previously mentioned. Within the considered territory there is a service network that includes facilities for each level of neonatal care, and a characteristic of the network lies in that for every higher level facility also lower levels facilities are provided in the same place. Each facility is characterized by a capacity, i.e., the amount of patients who can be simultaneously admitted: more precisely the capacity of the third level of care is given by the number of ventilated incubators available and the capacity of the second level by the number of incubators; the capacity related to all the three care levels combined emerges from the numbers of beds available for the mothers. As seen above, every mother-to-be should be admitted to a facility on a level appropriate to the foreseen newborn conditions; if places are available, she is admitted to the closest facility with respect to her district, otherwise to another facility chosen according to increasing distance order. At birth the newborn may present unexpected complications and require urgent transfer to a centre providing a higher level of care, at the same location or elsewhere, depending on the availability of levels of care and vacant places.

The aim of the simulation lies in i) checking the patients distribution among the existing facilities, ii) checking the assistance network ability of supplying a suitable service, in terms of admitting all patients sufficiently close to their home, and iii) possibly suggesting convenient adaptations in case of inadequate service.

In health care literature, and particularly for what concerns health care services planning, the problem of facilities location-allocation was discussed in (Toregas et al. 1971; Branas et al. 2000; Takinawa et al. 2006; Sahin et al. 2007; Mitropulos et al. 2006; Ratick et al. 2008;) with an optimization approach. The problem of perinatal facility planning was studied by (Galvão et al. 2002; Boffey et al. 2003; Galvão et al. 2006). All above papers solve the planning problem by means of optimization but the solution is given as the average, in other words the mean of admitted patients is considered. In this paper the detailed movement of newborns is obtained revealing all peak conditions. The simulation results report: patients admitted far from home, patients admitted out of the region, transfers among hospitals because of missing places. From the results useful suggestions may be obtained about suitable network resizing in order to improve service quality and reduce trouble due to distance and related costs.

## 2. Birth Assistance and Birth Centres

Pregnancy may take a physiological or a pathological course. Complications in pregnancy may include gestational diabetes, infections, foetal malformations, and so on. Such complications may cause problems during delivery and/or in the neonatal period, so a higher level of care should preferably be chosen in advance for such cases (Le Roy et al. 2006; Eberhard et al. 2008; Mayfield et al. 1990).

Birth may take a physiological or a pathological course too. Some complications, such as those due to foetal-pelvic disproportion, placental deformity, etc., may be foreseen, so a higher level of care can be planned. Others, e.g. foetal distress, haemorrhage, premature birth, etc., may be unexpected and require prompt referral to a higher level of care.

Mothers are assisted during delivery by a gynaecological-obstetric team and newborns by a paediatric-neonatology team. The care provided is generally classified on three levels, i.e. neonatal basic care, intermediate care for neonatal diseases and neonatal intensive care; such a classification is widely accepted in Europe and the USA, as reported in (Brann et al. 1980; Le Roy et al. 2006; Van Reempts et al. 2007; Zeitlin et al. 2004; Committee of fetus and newborn. 2004).

The main characteristics of each level of care are recalled below:

- the first level of care is provided in the case of uncomplicated pregnancies and is characterized by the following capabilities:

- assistance for the mother: continuous specialist assistance can be provided;
- assistance for the newborn: continuous neonatological assistance can be provided, a neonatological unit can be used for primary resuscitation;

- the second level of care is provided in the event of pregnancies and births at low risk and/or involving mild prematurity (pregnancies shorter than 30 weeks or a birth weight below 1.5 kg), and is characterized by the following capabilities:

- assistance for the mother: continuous specialist assistance can be provided, specialist monitoring equipment may be used during labour;
- assistance for the newborn: continuous neonatological assistance can be provided, a neonatological unit can be used for resuscitation, and incubators may be used;

- the third level of care is provided in the case of higher-risk pregnancies and/or severely premature births (before 28 weeks of gestation, or birth weights below 1.0 kg), and is characterized by the following capabilities:

- **assistance for the mother: continuous specialist assistance, with anaesthesiological, intensive care and other specialist consultants available; specialist monitoring apparatus can be used during labour;**
- **assistance for the newborn: continuous neonatological assistance, intensive care with artificial ventilation, and specialist consultants available; a neonatal intensive care ward is used.**

Each birth centre may be associated with various levels of care. Most centres provide only basic care, while a few specialist centres provide both first and second levels of care, and only a very few highly-specialized centres provide all levels of care.

Clearly, every pregnant woman should generally be admitted to a birth centre where the level of care is appropriate for any expected birth complications; in other words, a "level requirement" may be defined

## 3. The Problem

Let us consider a birth centre and all the levels of care it can provide, bearing in mind that there are three levels of neonatal care and, for each of these, the capacity in terms of births per year can be established from the distribution of the duration of the users' stay. More precisely, the capacity related to all care levels combined emerges from the number of beds available for mothers in the obstetric ward. In addition, the capacity of the third level of care is limited by the number of artificially-ventilated incubators available and the capacity of the second level by the number of incubators, while for the first level of care there are no such structural limitations. The site and size of the birth centres are fixed a priori. Recommendations for adjusting the size of a given centre may emerge from the solution of the model.

Let us consider a health district, i.e. a homogeneous built-up area that can be seen as a point in relation to distances. For each district and each level of care, we define the corresponding demand in terms of births per year (this demand can be extrapolated from the statistics of previous years).

As seen in the previous section, a pregnant woman should be admitted to a centre and occupy a place on a level appropriate to her needs. Let us consider a situation where she has occupied a place where first or second-level care is provided but her newborn presents unexpected complications and requires urgent transfer to a centre providing a higher level of care, at the same location or elsewhere, depending on the availability of levels of care and vacant places. In such a case, the newborn is transferred while the mother remains at the centre where she gave birth. Lower-level birth centres may thus become a source of further requests for the admission of newborn, adding to the above-mentioned requests coming directly from the urban nuclei.

## 4. The Model

Admission requests rise in a random independent way for every level and for every district, according to statistics extrapolated from past data. Every request is dispatched to a facility of the corresponding level, more precisely the closest one with available places both for the mother and the newborn. If the newborn conditions worsen then he/she is transferred to the closest higher-level facility, without moving the mother who remains in the first admission facility. The ratio of newborns needing transfer between different levels is statistically known from the past. The length of stay distributions are shown to be gamma functions with parameters obtained from past data.

All distributions parameters are obtained by elaborating data from patient discharge papers, which are compiled in correspondence to every patient exit from hospital and therefore for every newborn.

The model evidences the saturation of all facilities and therefore their bed occupancy ratio. Moreover all network malfunctions may be revealed, more precisely the amount of patients that are admitted far from home and the amount of newborns that are transferred to another facility because of missing places.

### 4.1. Model Implementation

The model is quite simple, therefore it can be implemented using many simulation languages. Here it was implemented in MicroSaint Student, which was at disposition, but it may be easily translated in any language similar to SIMAN-Arena. MicroSaint implementation has a graphical representation that is based on four basic elements: tasks, describing activities, arrows, representing activity sequences, rhombuses, representing decisions and striped rectangles, representing queues.

Our model implementation is reported in Figure 1, where task 1 is employed to start simulation, tasks 2-4 report all parameters utilized by the model, more precisely demand rate for each level and each district, all facility capacities and all distances (both district to birth centre and centre to centre). Tasks 5-7 are demand generators for the three levels; the arrival rate is the sum of all districts arrival rates while the district is probabilistically stated. Tasks 8-10 decide the dispatching of mothers and newborns and the possible newborns transfers. Task 11 represents mothers and newborns admitted to

facilities out of the region, tasks 12-13 manage the dispatching of transferred newborns. Task 14-16 are necessary for functional aims and, finally, tasks 17-19 respectively describe mothers admissions and second and third level newborns admissions.

Note that patients' movements from all districts towards all facilities and among facilities have been described by means of a small model.

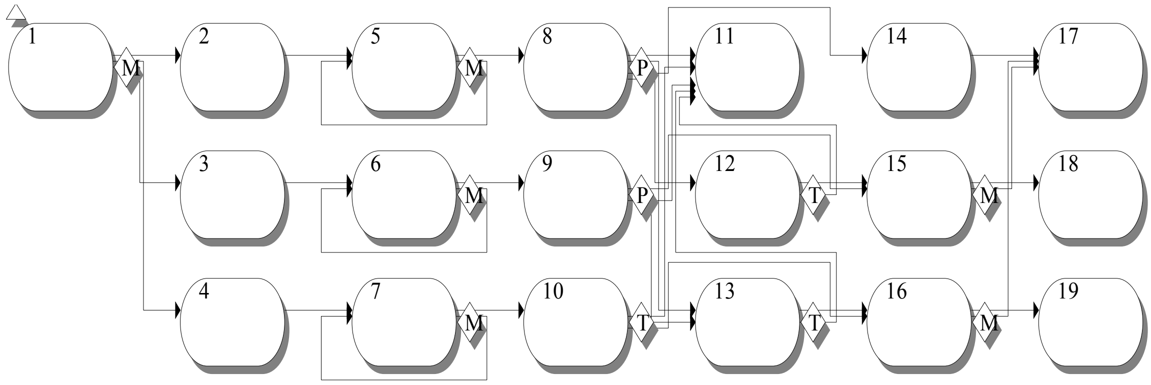


**Figure 1.** The model

### 4.2. Model Application and Results

The model was applied to the Veneto Region in North-East Italy, a region with a population of about 4,700,000 and about 43,000 newborns per year. In the region there exists 52 health districts and 41 birth centres, all of which have both first facilities, for a total of 632 places, and second level facilities, with a total of 245 places, while only 9 of them have the third level facilities with a total of 57 places. The length of stay is a gamma distribution with a mean of respectively 3.6 days for the first level, 6.5 days for the second level, 17.6 days for the third level. All the above data have been obtained from the regional statistical office.

The simulation reveals a lot of interesting results about the patients' movements and beds saturation. The saturation of beds for the mothers is 58.5%, the saturation of second level places is 61% and the saturation of third level places is over 99%. No first level newborn needs to be admitted out of the region, but the 21% are not admitted to the first choice birth centre and the 59.6% are constrained to be admitted to a facility over 15 Km far from home: that evidences that the first level assistance is over dimensioned but badly distributed on the territory; the same happens for the second level, for which only the 1,5% needs to be admitted out of the region. 47% patients cannot go to the closest centre and 25% are admitted to a facility 25 Km far from home. For what concerns the third level, we see that 64% are admitted out of the region and that evidences that the third level assistance is absolutely insufficient. If an improvement is to be obtained that shall be performed by means of an increase of places for the third level; a mild reduction of beds for the mothers and of second level places may be accepted; the first action requires an expansion of existing units, that means an increase of both ventilated incubators and specialized personnel; the second action may be simple. Obviously new distributions of birth centres on the territory would be desirable and may be easily simulated but that is much more complex to obtain in practice.

## 5. Conclusions

We have built up and implemented a simulation model describing in detail the movements of mothers-to-be and newborns among health districts and assistance facilities, where assistance facilities are classified according to three different levels corresponding to the severity of newborn conditions. The aim of the model lies in checking system effectiveness and efficiency in providing adequate care to patients close enough to their home. Simulation results permit to reveal assistance lacks and to suggest suitable correcting actions. The model has been implemented on a personal computer and applied to Veneto region but it can be easily applied to other Italian or foreign regions.

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