Discrete Event Simulation to Support Capacity Planning for Heart Failure Patients

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Abstract

Patients with heart failure (HF) are admitted to the hospital in a non-elective way. Receiving intravenous medication they are very limited in their activities of daily living (ADL) resulting in intense nursery care. To predict the needed capacity a distinction is made between currently admitted patients and patients that will be admitted in the near future.

Computer simulation is used to predict when new HF patients can be expected at the floor and when they will be discharged. The simulation model also provides information about the ADL status of the patients.

Former HF patients are used to predict when current HF patients that are already admitted at the cardiology department will be discharged.

The results of a test of both methods are presented and discussed.

1. Introduction

Patients with heart failure are admitted to the hospital in a non-elective way. The number of patients with duoric heart failure (HF) is still growing leading to increased mortality and (re-)admissions to the hospital [1, 2] although recently instituted out-patient heart failure programmes have a positive effect on mortality and morbidity, re-admission rate, quality of life, compliance and health costs, the burden of patients with heart failure admitted to the cardiology department is tremendous [3, 4]. The treatment for heart failure during the first days is often with intravenous medication. This means that they are very limited in their activities of daily living (ADL) resulting in intense nursery care. Over time the ADL status of the patient may change even so the treatment. To create optimal care, nurse staffing and planning of cardiology patients who have to be admitted electively to undergo other diagnostic or therapeutic procedures.

The question is whether a method can be developed that can help the management to adequately predict the number of heart failure patients and their ADL status on a day-to-day basis. To predict the number of patients present in the floor during the next days one has to distinguish two groups of patients: already admitted patients and the patients to be admitted. Such a method should be able:

1. to predict how the ADL status of the current patients will develop during their stay at the floor and when they will be discharged.
2. to predict when new patients will be admitted, their ADL at admission, the subsequent changes in ADL and when they will be discharged.

We hypothesize that the first goal can be met by using the available information about former HF patients with the same 'ADL-history'. It is assumed that these former HF patients are good predictors for the current patients.

We also hypothesize that computer simulation can be used to predict when new patients will be admitted and how long they will stay at the floor and how the ADL status will change during their stay.

2. Method

2.1. Patient data and patient trajectories

At the department of Cardiology of the Maastricht Academic Hospital the MAaStriCHt heart failure database (MASCH) contains data about all patients with heart failure admitted in the Maastricht University Hospital since January 1998. From the first of January 2000, also the ADL status and "waiting" status of the patients are recorded in MASCH. Every first entry of a patient in MASCH is called a first admission. This database is used to obtain information needed for this study.

During the first days after admission for heart failure a patient may need a lot of assistance when he or she is not able to perform the activities of daily living (these patients are called fully ADL dependent). After some days this situation may improve and the patient becomes partly ADL dependent. During the last period of the admission the patient may be able to perform all the activities (patient becomes ADL independent). However not all the patients follow these phases. Some patients will remain in the same ADL phase during their stay in the hospital while other patients skip one of the phases. Sometimes a patient cannot be discharged because his or her 'home' situation is not suitable anymore and a bed in a nursing home is not immediately available. From a cardiological point of view the treatment in the hospital has ended but the patient still occupies a hospital bed.

There are 14 possible paths through the different ADL phases and "waiting" status. Each patient will follow one of these paths. In these paths no distinction is made whether a patients dies or stays alive.

2.2. Simulation of new patients

To predict the capacity needed for new HF patients discrete event simulation (see Banks [5] and Law and Kelton [6] for more details about discrete event simulation) is used. A simulation model was designed that predicts the arrival date and length of stay at the floor. The model distinguishes patients admitted for the first time and re-admissions. The model will both predict the number of patients in the different ADL phases and the number of patients who are "waiting" as a function of time.

In the following the various parts of the model will be discussed. During the simulation each day at 12:00 pm the number of patients at the floor, the number of first admissions, the number of re-admissions, the number of patient that are fully ADL dependent, the number of patients that are partly ADL dependent and the number of ADL independent patients was recorded.

The simulation model considers all 14 different paths through the ADL phases. Each patient with heart failure will follow one of these paths after admission. In the model the time a patient will stay in each phase of a path is described by a probability distribution function (see Law and Kelton [6] for an extensive discussion about probability distribution functions and their applications). This probability distribution function is an analytic function that best fits the distribution observed in the patient database MASCH.

For each new patient admitted to the floor the simulation model determines which path the patient will follow in accordance with the observed frequencies. The duration of each phase is described by a probability distribution function. The best fitting distribution was selected using Stat::Fit, a tool incorporated in MedModel [7] and the parameters of these distributions were calculated.

In the simulation model the arrivals of the HF patients on the cardiology floor are modeled using arrival patterns. An arrival pattern indicates for each day the number of the patients that will be admitted as percentage of the total number of patients admitted during one year. Two arrival patterns, one representing the first admissions and the other representing the re-admissions, used by the model were determined using data from MASCH about patients admitted in 2000. The arrival patterns are exact copies of the arrival patterns of 2000. Care was taken that workdays in the year 2001 map to the same workdays in the year 2000. It is assumed that the absolute number of patients in 2001 will be the same as it was in 2000.

2.3. Matching current patients

Part of the problem is to predict when current patients will be discharged. In general a cardiologist can accurately predict which patients will be discharged in the next two days. For all other HF patients the probability that the patient will still be at the floor after several days has to be determined. This is done by searching for matching patients out of all HF patients admitted in 2000 with exactly the same characteristics and using them as predictors for the discharge date and ADL phases. The following characteristics are matched: re-admission or not, ADL status on admission, ADL history, number of days on the floor (T_1).

The probability that a patient is still at the floor T_2 days from now ($T_2 > 2$) is equal to the fraction of the matched patients from MASCH whose stayed at least T_1+ T_2 days.

3. Results

3.1. Patient data and patient trajectories

The arrival patterns were obtained from MASCH. In 2000 233 patients were admitted for the first time with heart failure. Data concerning ADL and "waiting" status were available from 213 patients that were admitted for the first time. The number of re-admissions was 123 in that year. Data concerning ADL and "waiting" status were available from 114 patients.

No dependencies between the length of stay in the different ADL phases were found. Although a weekly pattern in the average number of admissions was found, the average number of admissions per day of the week does not differ statistically significant.

To determine the distribution function that described the duration of the different phases, patient data from MASCH was used. For some phases in some paths data of only a few patients are available. To determine the distribution functions for these phases patient data of different paths were combined. For example to determine the distribution function describing the duration of the totally ADL dependent phase for the first admission, data of all patients that were in that phase was used.

To assess the quality of the methods the situation on the floor of the Maastricht University Hospital was predicted for two two-week periods starting at January 15th and February 15th 2001. The first period starting with January 15th 2001 was chosen because it was not too close to the end of 2000.

3.2. New patients

The results of the simulation model for first admissions and re-admissions for January 15th and February 15th 2001 are shown in Figure 1 and Figure 2 as an example. These data are an average of 100 simulated years (100 replications). In Figure 3, Figure 4 and Figure 5 respectively the number of fully ADL dependent patients, partly ADL dependent and ADL independent patients presented in the floor are shown for the period starting from January 15th 2001. Similar results concerning the number of patients in the different ADL phases are found for February 15th 2001

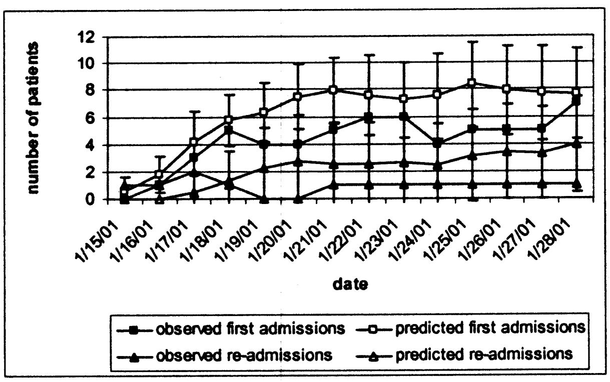

Figure 1: The number of patients at the floor admitted because of HF at or after January 15th 2001. The vertical lines indicate the 99 % confidence interval.

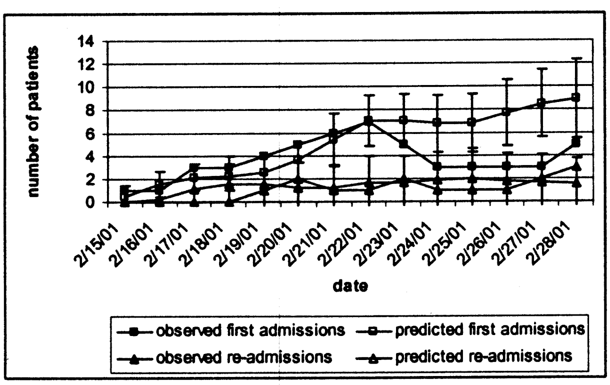

Figure 2: The number of patients at the floor admitted because of HF at or after February 15th 2001. The vertical lines indicate the 99 % confidence interval.

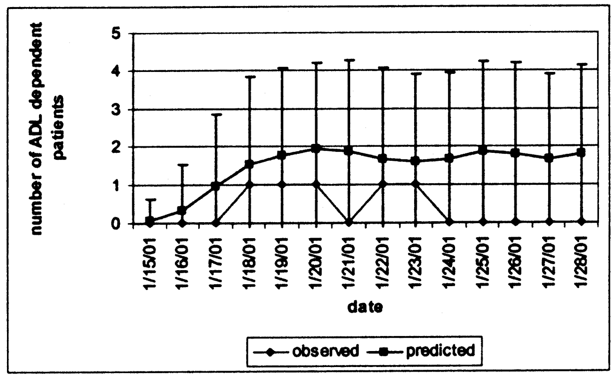

Figure 3: The number of fully ADL dependent patients admitted because of heart failure admitted at or after January 15th 2001. The vertical lines indicate the 99 % confidence interval.

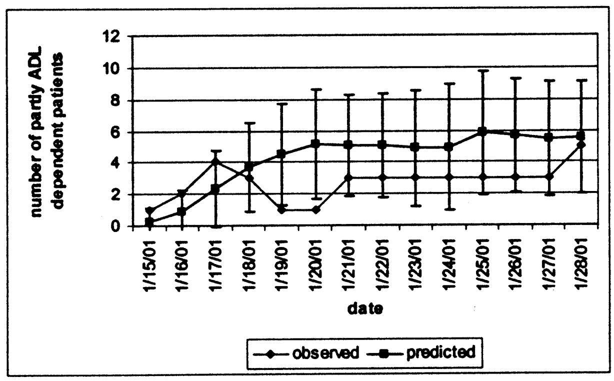

Figure 4: The number of partly ADL dependent patients admitted because of heart failure admitted at or after January 15th 2001. The vertical lines indicate the 99 % confidence interval.

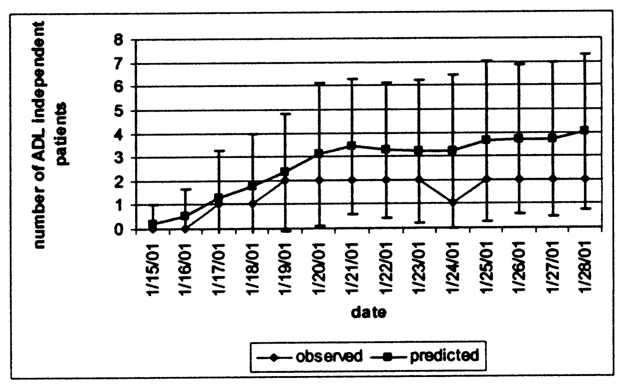

Figure 5: The number of ADL independent patients admitted because of heart failure admitted at or after January 15th 2001. The vertical lines indicate the 99 % confidence interval.

3.3. Current patients

The results of the procedure described above to predict the stay of the current patients are shown in Figure 6 and

Figure 7. Only patients that will not be discharged within 2 days are taken into account here. The few patients who were admitted in 2000 but were still hospitalized on the chosen days were excluded.

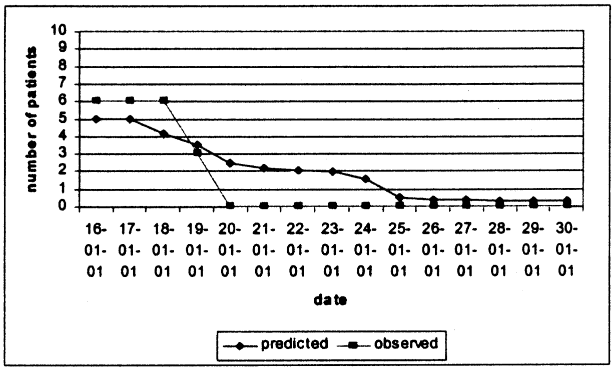

Figure 6: Current patients at January 15th 2001. One patient could not be matched with patients admitted in 2000.

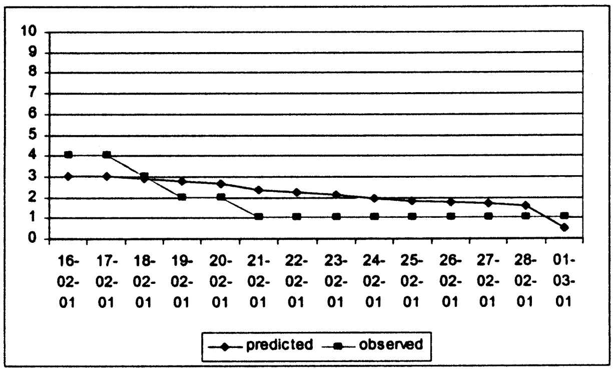

Figure 7: Current patients at February 15th 2001. One patient could not be matched with patients admitted in 2000.

4. Discussion

In January 2000 an intensive out-patient clinic program has starts to prevent (re-)admissions. This will influence the number of HF admissions. However the number of HF patients has increased during the last years. Both factors will influence the results of the methods.

4.1. New patients

Figure 1 shows that the predicted values starting from January 15th 2001 are higher compared to the observed values. This can be explained by the difference in the number of re-admissions in 2000 and 2001.

In Figure 2 the number of first admitted patients decreases strongly at February 23rd (Friday) and February 24th (Saturday). At Sunday February 25th a local three-day holiday (Carnival) started. The cardiologists tried to discharge a patient when it was possible from a medical point of view so the patient could be at home during this holiday. During this holiday no patients are admitted. Probably patients postpone their visit to a GP or cardiologist until after the holidays. The simulation model does not yet take into account public holidays and their effects on the admission of patients and discharge of patients. Since most holiday periods do not recur at the same dates each year the influence of holidays have to be modeled as a correction.

4.2. Current patients

In Figure 6 the predicted number of patients at the floor is higher compared to the actual number of patients. At January 19th (Friday) and January 20th (Saturday) the actual number of patients decreases sharply. In general a cardiologist want to discharge a patient when it is possible from the medical point of view. However for the patient it is more relaxing to be at home during the weekend than to be in the hospital. Therefore a patient will be discharged more often on a Friday and a Saturday.

Sometimes no match with an in 2000 admitted HF patient can be made and therefore no prediction of the discharge date can be given.

5. Conclusions

The presented methods to predict the needed capacity at the department of cardiology provide promising results. The influence of weekends and public holidays on the discharge date should be incorporated.

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