Applying Hybrid Tokens to the Estimation of the Therapeutic Outcome of Psychiatric Treatments

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In mental health care clinical pathways determining the form of therapy that has to be administered are highly controversial and have not been officially established. However, surveys indicate that different treatments of the same mental disease can lead to different therapeutic outcomes. This has a direct influence on the number of future patients of the health care providers and thus on the system's input and output including treatment costs and quality of care.

In this paper we use computer simulation to examine the outcome of different treatments for mental disorders in a psychiatric hospital. The compliance of the patient, that is the motivation for taking part in the treatment, is crucial for the success of a therapy. In case of a discontinuation the probability of the mental disturbances occurring again is higher than in the case of a successful completion. As the in-patients' parameter compliance is changing continuously during the treatment we need a simulation technique allowing continuous attributes of entities in a discrete-event-driven system. We use the introduced concept of hybrid tokens in stochastic Petri nets for modelling the treated in-patients with both discretely and continuously changing attributes. For that purpose, a sufficient mathematical description of the in-patients' mental parameters and their development over time has to be derived. In doing so, a comprehensive statistical analysis has to be performed. The provision system and the resulting Petri net are comparatively simple. Instead, a high number of tokens that has to be created and the computation of their attributes during the simulation run are the challenges that we are facing. After building the simulation model of the therapy processes we were able to run experiments by variegating characteristics and treatments of the patients and observe the system's output.

We believe that the implemented model can provide a decision support for physicians and therapists. It will enable the estimation of the therapeutic outcome and thus the choice of the most promising treatment according to the patient's mental disturbances.

Introduction

The method of computer simulation finds use in a large number of application fields, but spread and acceptance are still very different. In the majority of cases, simulation is applied to rather technically oriented problems than non-technical application fields involving soft and qualitative aspects. This is often the case in the area of medicine and health care. Usually, difficulties do not occur when logistic chains such as patient flow or bed occupancy in a hospital are modelled, but they arise when processes where human parameters and behaviour are to be considered. This can especially be observed in the field of mental health care as mental disorders are very complex and difficult to examine. Psychological parameters can play a decisive role in an according model.

Nevertheless, computer-assisted planning is of great interest for decision makers and planners of psychiatric services.

The pressure to control health care spending requires a reliable method for improving the efficiency of a health care system and its quality. Computer simulation can be used to analyse and optimise existing structures and processes of a provision system [8] as well as evaluate effects of changes in parameters or processes. For each variation investment and treatment costs can be computed and compared. [1]

Furthermore, prognoses can be made about the future workload of health care providers depending on the expected number of patients and their different medical conditions. In every case the quality of care is of particular interest and is to be improved or, at least, has to be maintained independently of possible actions taken.

One example question is the estimation of the influence of a particular form of therapy on the therapeutic outcome.

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In Germany somatic treatment follows strict clinical pathways determining the form of therapy that has to be administered. In mental health care clinical pathways are highly controversial and have not been officially established. The chosen therapy is within the sole discretion of the psychiatrist or psychotherapist and depends, for example, on the education of the attending physician or the focus and specialisation of the medical facility. However, surveys indicate that different treatments of the same disease can lead to different therapeutic outcomes. [6] This has an impact on the health care system including the number of patients and with it the workload of health care providers and overall costs.

Therefore, we would like to use the method of computer simulation to estimate the influence of different treatments of in-patients with mental disorders in a psychiatric hospital. This study requires a detailed model of the treated patients as the compliance, that is the motivation of the patient for taking part in the treatment, is crucial for the success of a therapy.

Each patient shows a different compliance to different kinds of treatments, based on parameters such as motivation or mood. As these parameters are changing continuously during the treatment we need a simulation technique allowing continuous attributes of entities in a discrete-event-driven system. For that reason we would like to apply the introduced concept of hybrid tokens in stochastic Petri nets to model the treated in-patients with both discretely and continuously changing attributes.

We believe a model like this might provide a decision support for physicians and therapists. It might enable the estimation of the therapeutic outcome and thus the choice of the most promising therapy according to the patient's mental disturbances. The collaboration with the holding company of a group of German psychiatric hospitals enables us to analyse the processes of psychiatric therapies in stationary care and to collect and interpret the necessary data for the simulation model.

In Section 1 of the paper we describe the course of psychiatric treatments as they could be observed in one of the cooperating hospitals. After a brief introduction on Petri nets, Section 2 explains the basic principles of hybrid tokens. Afterwards the derived simulation model and the collected input data and its analysis are described. It is followed by details on the implementation.

In Section 4 we describe several simulation runs for calibrating the model and finally present simulation results. The paper closes with an appraisal of the results.

1 Psychiatric treatments

1.1 Treatment of mental disorders in Germany

The treatment of mentally ill people can be carried out in many different ways depending on the kind and seriousness of the disturbances. Possible are ambulant treatments in out-patient departments and psychiatric or psychotherapeutic practices. In day hospitals patients stay for the day, availing different forms of therapy and are allowed to go home for the night. People with serious mental disturbances requiring a stationary treatment are admitted to hospitals. Reasons may be the need for a supervised drug therapy or if they endanger themselves or other people.

After admission, diagnoses are proposed including a leading diagnosis and, if necessary, one or more secondary diagnoses covering comorbidity. According to these diagnoses and the condition of the patient different treatments are possible. In a psychiatric hospital these include the prescription of drugs such as antidepressant or mood stabilizers and setting up a psychotherapeutic treatment. Possible treatments for addictive disorders are among others psychoanalysis, cognitive behavioural therapy or interpersonal therapy in individual and group sessions [6].

One important advantage of examining only hospital care is that the in-patients are under permanent medical observation. By contrast, during an ambulant treatment there are different happenings possible having an influence on the therapeutic outcome but cannot be observed and measured. Furthermore, the data acquisition and management in hospitals is usually clearly organised and is subject to certain standards.

Due to the complexity of mental disorders and the varying psychological conditions of patients we chose to focus on addictive disorders where cause and effect are slightly clearer and better explored. The group of addictive disorders covers among others the abuse of alcohol and tobacco as well as opioids or cocaine, whereas alcoholism is the most prevalent disorder. There a relapse is often associated with an acute withdrawal syndrome forcing the patient to go back into a stationary care where the return is recorded.

Other relapses, a depression relapse for example, cannot be diagnosed that easily as symptoms are usually not immediately visible or acute. The patient can also choose an ambulant type of care instead of being readmitted and thus does not appear in the data records of the hospital.

1.2 Influences on the Therapeutic Outcome

At the beginning of the treatment, physician and patient agree upon several therapy goals. Additionally, the patient's mental and physical state is rated by the physician on a defined numeric scale. During the discharge interview the current condition of the patient is compared to this numeric value and the achieving of the defined goals is evaluated. This results in the therapeutic outcome and is always only a subjective impression both of physician and in-patient.

In opposition to somatic medicine it is not possible to gain ambiguous, measurable and objective data and the actual outcome of a treatment can have diversified shapes. Especially difficult is the review of the therapy goals as it has a qualitative non-numeric result. For that reason, we simplify the therapeutic outcome being either the successful completion or the discontinuation of the treatment. This definition follows the idea of the remission being a marker of a patient's wellness. [5]

Besides different forms of therapy, there are additional factors influencing the therapeutic outcome. The most important one is the so-called compliance. It describes the motivation of the patient for taking an active part in the therapy and complying with the instructions of the medical personnel. This parameter plays a decisive role in psychiatric treatments. If the in-patient is not compliant the probability of discontinuating the therapy and leaving the psychiatric facility is high.

The level of compliance at the beginning of the therapy varies from patient to patient and changes continuously during the course of the treatment while different forms of therapy can cause different development courses. [3] The change can be completely independent of occurring events, although some can have an effect, for example happenings in therapy sessions or even the visit of relatives during the hospital stay. Additionally, the compliance depends on further mental attributes that may themselves have a continuous dynamic.

As a result, all these parameters and their discrete or continuous change over time have eventually an impact on the therapeutic outcome.

2 Modelling approach

2.1 Coloured Stochastic Petri Nets

Stochastic Petri nets are a common paradigm for modelling discrete-event systems [9] where the system state changes discretely at countable points in time. These points are determined by the occurrence of discrete events that may change the state of the approximated system. This state is described by all variables and attributes required for giving a complete image of the system at a particular time relative to the objectives of a simulation study. The time when each type of event will occur next has to be stored in an event list, called future event list. The simulation run is continued as long as there are scheduled events in the list.

In Petri nets the complete model is represented as a graph consisting of places (states) and transitions (state changes due to occurring events) that are connected by directed arcs. The places of the net can contain any number of mobile elements of the system, referred to as tokens. These tokens are moved from place to place by the "firing" of the transition representing an event occurring in the system. So-called immediate transitions fire instantaneously when becoming enabled, whereas timed transitions fire with a certain time delay.

Coloured stochastic Petri nets extend the concept by adding attributes to the tokens. [4] The firing of a transition not only changes the distribution of tokens but can also modify the attributes of the tokens. With coloured Petri nets, discrete-event systems can be modelled containing distinguishable mobile entities with specified attributes.

The most important advantage of Petri nets is the graphical representation that gives a clear and intuitive overview of the system. During the simulation run, the user is able to track the movement of tokens through the system. The whole definition of the system is revealed without hiding information or functionality. Furthermore, the net is easily extended by adding places and transitions – even for a user without expertise in modelling techniques. This is of interest to us, since the model we are developing is to be used by medical, rather than modelling, experts.

For that reason we decided to model the process of a psychiatric treatment with the aid of coloured stochastic Petri nets. However, the involved tokens, i.e. patients in the medical facility, are characterised not only by discrete but continuously changing parameters. Their development course is crucial for the output of the system. Therefore, we also had to enable the modelling of continuous token attributes in Petri nets.

2.2 Hybrid tokens

For modelling a discrete-event system with mobile entities described by hybrid attributes we introduced in [2] the concept of hybrid tokens in coloured stochastic Petri nets. As shown in Figure 1 the new token definition includes not only discrete but also continuous token attributes.

In addition, the new defined token contains functions describing the continuous change of these attributes, typically, implemented by differential equations describing the rate of change over time.

Therefore, a hybrid token has its own attribute dynamics which are independent of system events. Regarding that the continuous attributes are not to be precomputed, the integration steps have to be included in the global event list for proceeding the simulation run. That way, the introduced approach combines the idea of hybrid simulation with still distinguishable entities moving around in the system.

Considering the hybrid token extended by continuous attributes as well as dynamics, there are several interactions possible between different token attributes. They are no longer only influenced by events but by changing values of other token attributes. The following interdependencies are possible:

- A change in the value of either discrete or continuous attributes may cause a change in the value of a continuous attribute.
- A change in the value of either discrete or continuous attributes may cause the relationship governing a continuous attribute to change at a particular time.
- A continuous attribute achieving a threshold value may cause a change in the value of another continuous attribute.
- A continuous attribute achieving a threshold value may cause the relationship governing another continuous attribute to change at a particular time.

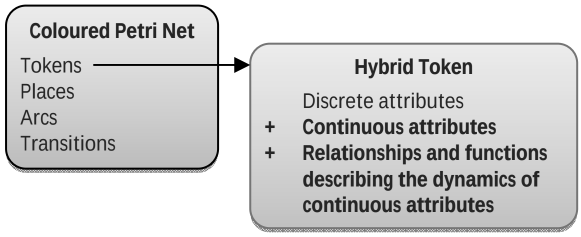

Figure 1. Components of coloured stochastic Petri net with hybrid tokens

All other components of the Petri net remain unmodified but their functionality has to take the attribute dynamics of the hybrid token into account. Transitions can be enabled either by values of discrete or continuous token attributes and in the same manner change all attribute values as well as attribute dynamics when they fire. There are also several types of possible interactions between system events and hybrid tokens:

- A discrete event may cause a discrete change in the values of discrete or continuous token attributes.
- A discrete event may cause the relationship governing a continuous token attribute to change at a particular time.
- A continuous token attribute achieving a threshold value may cause a discrete event to occur or to be scheduled.

The modelling approach of hybrid tokens adds attribute dynamics to the Petri net but keeps them separated from already existing dynamics due to the occurrence of system events. The graphical representation of the system is kept clear and easy to read.

3 The model

3.1 The derived Petri Net and hybrid tokens

Based upon the identified processes of the provision system briefly described in Section 2 the stochastic Petri net is small consisting of only a few places and transitions shown in Figure 2. Depending on the medical review the patient is admitted and after proposing the diagnoses, different treatments are administered. At every point in time it is possible that the patient's compliance falls below a certain threshold causing the patient to discontinue the therapy. Otherwise the patient leaves the facility after completing all treatments.

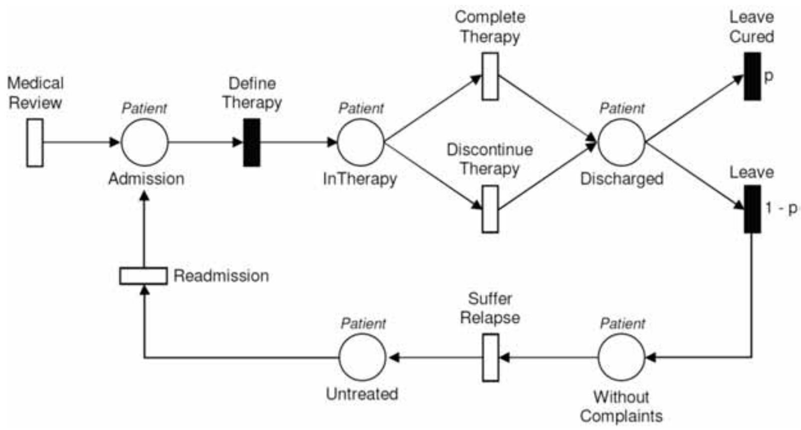

Figure 2. Petri net of health care service in psychiatric hospital

With some probability the mental disturbances occur again after a certain amount of time and the patient is readmitted. In case of a previous discontinuation this probability is higher.

All places of the net can contain tokens of the type *Patient*. A patient in this system is characterised by the following attributes:

- `nDiagnosis`: integer (discrete)
- `nCompliance`: double (continuous)
- `nThreshold`: double (discrete)
- `bDiscontinue`: boolean (discrete)

The variable *nDiagnosis* stores the leading diagnosis determining which therapies are to be administered. The previously mentioned compliance is modelled as continuous token attribute *nCompliance*, whose initial value is randomly distributed and, additionally, depends on *nDiagnosis* as different diseases and comorbidities result in higher or lower motivation.

The parameter *nThreshold* specifies the lowest value *nCompliance* is allowed to reach before the in-patient will discontinue the therapy. The logical attribute *bDiscontinue* marks this state and is set to `TRUE` whenever this case occurs.

Substance	Rate of leading diagnosis	Rate of secondary diagnosis
Alcohol	0.088	0.755
Opioids	0.011	0.037
Cannabinoids	0	0.037
Other/multiple abuse	0	0.072

Table 1. Frequencies of diagnoses of different addictive disorders.

For being able to build a computer model from this conceptual model, the according data for the described variables has to be collected and analysed. The mathematical relationships are derived from the data record of the psychiatric hospital.

3.2 Input and output data

The cooperating psychiatric hospital is a clinic for psychiatry and psychotherapy and provides psychiatric care for children, adolescents and adults. The set contains all patient records from November 2005 to October 2008. During that time 432 in-patients were treated. According to the question we would like to answer with the simulation and the process chain we have to analyse frequencies and mathematical relationships between several parameters.

Diagnones. First, the number of in-patients with addictive disorders was examined: In 242 cases an addiction was set as leading or secondary diagnosis or both.

Table 1 shows frequencies of the abuse of the different psychotropic substances. It is noticeable that alcoholism is the predominant disorder but is usually set as secondary diagnosis.

In 79 percent of those cases the leading diagnosis is stated as personality and behavioural disorder as the abnormal consume of alcohol causes pathological changes in personality and behaviour.

Initial Compliance. Table 2 shows the initial motivation of the patient for taking part in the treatment. In the hospital's questionnaire this motivation can take only 5 qualitative values. For purposes of computation we declare the numeric equivalent as shown in the second column of Table 2. We let the given motivation be the mentioned parameter compliance.

Data analyses show that the motivation for the therapy of addictive disorders is exceptional high. One explanation might be that 92 percent of the patients came on their own free will and were not referred by another institution.

Furthermore, it has to be taken into account, that there is a certain inhibition threshold of telling the physician about being less or not motivated. Second the table shows the number of therapy discontinuations for each stated motivation. In the available data record the overall discontinuation rate is 0.3306. Thus nearly one third of 242 in-patients with an addictive disorder left the hospital before the therapy was completed.

As expected the rate is much higher if the patient is less motivated: About two thirds of the in-patients being less motivated discontinued the therapy.

Therapy forms. Finally, we analysed the combination of different treatments – resulting in the therapy form – and the according number of discontinued and completed therapies. Due to the high variety of possible treatments the combinations are manifold. Therefore, we only keep treatment combinations that were administered in at least 3 cases and grouped similar combinations for comparison. Some of the results are shown in extracts in Table 3.

For reasons of data security and simplification the treatments are named alphabetically and will mostly not be explained. In cases of D and E the appended number signifies either individual session (1) or group sessions (2). Treatments are among others behaviour or analytical orientated therapies as well as psychotherapeutic relaxation techniques and counselling interviews.

Additionally, somatic comorbidities can be treated (G) and patients can be medicated with psychotropic drugs (H).

Motivation	Numeric equivalent		Rate of cases	Rate of discontinuation
Very Motivated	4		0.1529	0.2703
Well Motivated	3		0.6901	0.3353
Motivated	2		0.1281	0.3226
Less Motivated	1		0.0248	0.6667
Not Motivated	0		0	0

Table 2. Motivation at the beginning of the treatment and rate of discontinuation

Motivation	Lower bound	Upper bound
Very Motivated	3.0001	4.0000
Well Motivated	2.0001	3.0000
Motivated	1.0001	2.0000
Less Motivated	0.0001	1.0000
Not Motivated	0	0

Table 4. Numeric boundaries for non-numeric motivation values.

Therapy	A	B	C	D1	D2	E1	E2	F	G	H	Cases	Discontinuation rate
1		●			●					●	13	0.3846
2		●			●				●	●	49	0.2857
3		●					●			●	10	0.1000
4		●					●		●	●	28	0.0714
5		●				●	●			●	5	0.0000
6	●	●		●	●					●	3	0.6667
7	●	●		●						●	3	0.3333
8	●	●		●	●			●			17	0.5294
9	●	●	●	●	●					●	3	0.6667
10	●	●	●	●	●			●			5	0.4000

Table 3. Number of different administered therapy forms and rates of discontinuation

As the small number of cases for each therapy form shows is that the results can only provide an indication on the actual relationships but are not completely statistically reliable.

Therapies 1 to 5 show three different things: First, the additional treatment of somatic comorbidities (G) decreases the number of discontinuations as the rates are lower in therapy 2 and 4 compared to 1 and 3. Due to the improved state of health it is likely that the compliance of a patient increases. A further positive impact besides the mere treatment might have the additional attention that the patient appreciates.

Second, treatment E2 seems to be more successful than treatment D2 as the rates are lower in therapy 3 and 4 compared to 1 and 2. Third, for treatment E it might have a positive effect if the patient takes part in additional individual sessions. The last observation might also be shown by the differences between therapy 6 and 7 where additional group sessions seems to have no further positive effect.

Since nearly all in-patients in the hospital took part in individual sessions we were not able to retrieve the necessary mathematical relationships. But the positive effect on the remission of symptoms in individual sessions in comparison to group sessions could be observed in different surveys. [7]

Therapies 6, 8, 9 and 10 imply that treatment F has a larger positive effect on the patients' compliance than treatment H (psychotropic drugs). The patients' initial motivation cannot explain the result directly. For example, the mean motivation at the beginning of therapy 1 is about 2.8980 and at the beginning of therapy 2 about 2.8462. Thus the therapeutic outcome of therapy 1 is lower than the outcome of therapy 2 although the patients were better motivated.

3.3 Details of the implementation

This section describes how the derived statistical information is implemented in the simulation model and computed during the simulation run.

Initialisation of parameters. The discrete token attribute *nDiagnosis* is distributed according to the frequencies listed in Table 1 and set to a discrete integer value between 1 and 4. The initial value of *nCompliance* is set by random according to the frequencies of the motivation of the in-patients at the beginning of the therapy. Further analyses showed that there are no significant differences in the initial motivation between the four groups of addictive disorders listed above.

Therefore, we can handle the initial value for each diagnosis equally. For getting a certain variety between patients with the same motivation, the values are uniformly distributed within the boundaries shown in Table 4. The according threshold for the patients' minimal compliance is uniformly distributed between 0.0 and 0.1, because even a not motivated patient will not immediately leave the hospital.

Integration method. The most expensive routine is the computation of the differential equation governing the behaviour of the continuous token attribute over time. In our previous work we simply set a constant step size prior to the simulation run determining constant intervals at which the current values of continuous attributes are to be computed – for all tokens at the same time. After updating the value it is immediately checked if one of the termination conditions is fulfilled, in our example if *nCompliance* is below *nThreshold*.

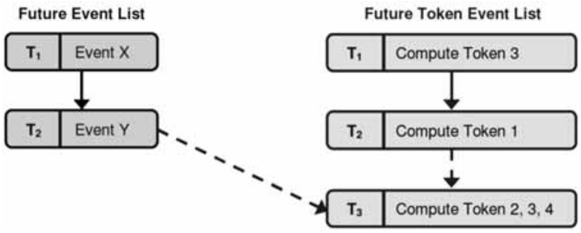

Figure 3. Structure of future event list and future token event list and connection between them

This approach was sufficient for developing the concept of hybrid tokens while working with fictional data, but it results in a large integration error.

As we are now interested in concrete simulation output we implemented an iterative integration method that chooses the largest possible step size with respect to the error and the termination condition. The method decreases the step size iteratively until the error of the computed compliance value is below a certain limit of tolerance. For our purpose the integration procedure is extended by a second step: If the error is acceptable at step size h the method checks if the termination condition would be fulfilled by the value of the continuous attribute, i.e. if *nCompliance* is smaller than *nThreshold*. If that is not the case, the value of the attribute can be updated and the point in time when it has to be computed next is determined by the current simulation time plus the step size.

For that purpose it is helpful to store the point in time when each token has to be updated in a separate list structured similarly to the future event list of the simulator. We call this list the future token event list illustrated in Figure 3. Due to the previously described interactions between different token attributes it is necessary to update all other dependent attributes after computing the new value of the continuous one.

As the occurrence of discrete events in the system may cause a change in the token's attributes or relationships it is necessary to start the computation of the continuous attribute of the affected tokens at the time of the event. Therefore, an additional event has to be scheduled in the future token event list, illustrated in Figure 3 with Event Y causing a third event to be scheduled in the token list. Time T_2 of Event Y corresponds to time T_3 of the token event. Summarised, the future token event list stores points in time when the next value of a continuous attribute has to be computed. The simulation run is continued as long as there are scheduled events in either the future event list or the future token event list.

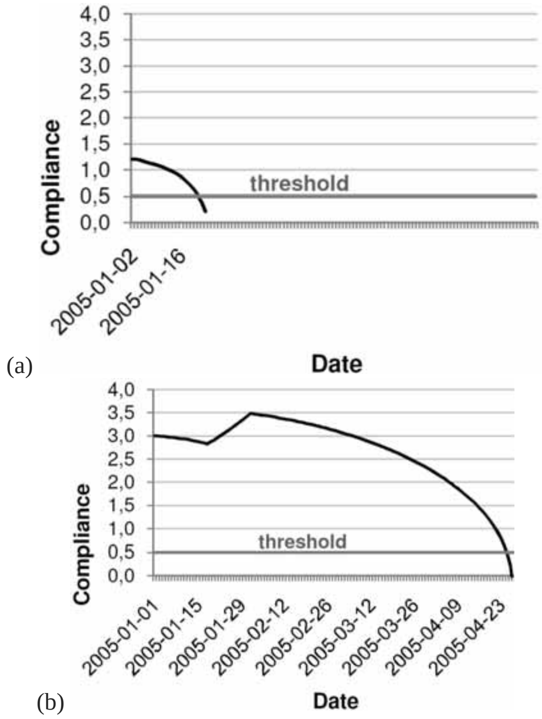

Figure 4. Example course of the compliance for two different tokens.

4 Simulation experiments

4.1 Deriving the development of the cmopliance over time

As the change of the compliance of the patient is regarded as continuous we have to find a suitable differential equation for the rate of change in time of the compliance. Considering the high number of patients not completing their therapy the compliance is expected to decrease fast during the therapy depending on different forms of therapy.

As we were not able to derive the differential equation directly from the data set we let it be simple (1) modelling a steady increase or decrease and run several simulations testing different variations and coefficients estimated from the data set. Thus the model is successively improved by calibration.

$$\frac{dx}{dt} = c\,\frac{t}{x} \tag{1}$$

Although it is more likely that the compliance is a complex variable depending among others on the mood of the patient we are only able to consider the given motivation of the in-patients as compliance without being influenced by other continuous parameters as they are not available.

Different behaviours of the compliance. At the beginning of the therapy the parameter compliance decreases fast as withdrawal symptoms lower the mood and thus the motivation of a patient. If the initial motivation for taking part in a therapy was low the probability that the value falls below the defined threshold is high.

Therefore, patients with low motivation discontinuing the therapy stay fewer days in hospital than leaving patients with a higher motivation. The data set slightly suggests this correlation. For that reason, the coefficient c in the differential equation is set to $-6\mathrm{E}^{-03}$ following the information that was derived from the samples. Usually, after three days the worst withdrawal symptoms are gone and between seven to ten days most of the symptoms disappear. This has a positive effect on the sense of wellbeing as somatic symptoms cease weakening the patient. Therefore, we set c to $-3\mathrm{E}^{-03}$ and after another 5 days to $-2\mathrm{E}^{-03}$. If the motivation is below 1.0 after that, i.e. the patient is less motivated, we leave the equation and coefficient unmodified. As a result the value will decrease further and, eventually, fall below the threshold. If the patient is still motivated after the withdrawal we assign the coefficient c a positive value, for example $6\mathrm{E}^{-03}$ modelling a fast increase in the motivation.

We assume that the compliance starts to decrease slowly after the first elevated mood as long as the therapy continues. The negative coefficient c is set depending on the administered treatment combination, described in Section 3.2. Again, we performed simulation runs for retrieving suitable values for c. Figure 4 shows two examples for possible developments of the compliance over time. The value for the first token was below 1 after eight days of withdrawal. Therefore, the value continues to decrease. The compliance of the second token was still high and the coefficient was set to a positive value causing an increase. After another week c is set to $-1\mathrm{E}^{-03}$ and the compliance starts to decrease again.

The third possible course of compliance is equal to the course of the second token in Figure 4. But at a certain point in time the therapy is completed successfully while compliance is still above the threshold. The planned length of the hospital stay is, as derived from the data set, normally distributed with different parameters depending on the form of therapy.

Therapy	A	B	C	D 1	D 2	E 1	E 2	F	G	H	Cases	Discontinuation rate
1		●			●				○	●	13	0.2942
2		●			●				●	●	49	0.2857
3		●					●		○	●	10	0.0693
4		●					●		●	●	28	0.0714

Table 5. Rate of discontinuation with changed forms of therapy

Validation. Data resulting from the system's behaviour can be used for checking the simulation output and comparing it to observed data. For our purpose, the ratio of completed and discontinued therapies is of interest as well as the length of the hospital stay in case of discontinuation. Unfortunately, we only have a few data samples as the date when the patient left is not always documented in the available data set.

After calibration of the model we chose to compute a scenario of one year length and only five replications, considering the immense computational effort caused by the integration for each token in the model. We then compared the computed rates of completed and discontinued therapies with the observed rates. Although the widths of the confidence intervals are expectedly large the computed rates approximate the observed values.

Also the length of stay in case of discontinuation is approximated. But as we used some parts of the data for calibrating the model this result only reveals that there are no influences in the model having an unintended effect on the output.

For a complete validation we would need an additional independent set of samples. Another way of testing the simulation output could be to compare the cases of discontinuation from the experiment with those patients being readmitted to the hospital. But due to the sample size covering a too short time period for that purpose such a comparison was not possible as only a few patients had relapses within four years.

4.2 Example scenario

As mentioned above, we are not able to make reliable statements on the basis of the available data set and its limitations. But since we intend to test the hybrid token approach we performed several simulation experiments. One is presented in this section.

The performed analysis of the available data implies that the treatment of somatic comorbidities has a positive effect on the therapeutic outcome, presumably due to the patient's improved state of health. In a simulation experiment we now increase the number of in-patients who are administered a somatic treatment. We did this for those cases were treatment combinations are equal except for the somatic treatment. Using the examples from Table 3, we added a somatic treatment (G) to therapy forms number 1 and 3. It results in a slower decrease of the compliance caused by the different coefficients c and has a positive effect on the number of discontinuations as shown in Table 5.

Further scenarios might be increasing the number of patients being administered therapy form F instead of additional pharmaceutical treatments. In order to do that, it has to be clarified under which circumstances pharmaceuticals have to be used, for example if patients endanger themselves. According to past surveys a possible scenario will be examining the differences between individual and group therapies as soon as the according data will be available.

5 Conclusions

In this paper we described the efforts made to apply the previously introduced concept of hybrid tokens in coloured stochastic Petri nets to the modelling of in-patients in psychiatric treatments. For that purpose, we not only had to improve the methods for the computation of the tokens' continuous attributes, but also had to collect and analyse the according data describing the system, i.e. the in-patients' characteristics and administered treatments. After building a simulation model of the therapy processes we were able to run different simulation experiments by varying characteristics and treatments and observe the system's output. As we are now using an iterative integration method the computational expense is increased whereas the error of the method is decreased.

Caused by the limited sample data we had to make several assumptions and were not able to retrieve all desired information. Due to the length of hospital stays, the sample size covering nearly four years of therapies is, with respect to the limited number of patients during a year, too small for comprehensive and statistically reliable analyses. Another reason is that the variety between different patients is very high and thus they are hard to compare.

Unfortunately, data from earlier years are not completely digitised and are also existent in a different form as the data acquisition tool was changed in 2004. Furthermore, as the results form more detailed questionnaires, filled by the in-patients themselves at several points in time during their treatment, were not available yet, we were not able to evaluate the actual course of the compliance. These questionnaires are part of a new concept for evaluating the quality of care and are not completely installed yet.

However, the currently available data shows that it is possible to retrieve the desired information from the data set. When the required amount of data will be available, comprehensive analyses will be performed to ensure the detected mathematical relationships. The next steps include gathering data from other hospitals and comparing the administered treatments depending on the kind of addictive disorders. Second, other disorders could be examined, for verifying the coherences and discovering more interrelationships.

One of the challenges in implementation is the suitable quantification of subjective data. Probably, the most obvious example in our simulation model is the initial motivation of the patient stated at the beginning of the therapy. There are five discrete values having different meanings for different patients. Due to that it is possible that the actual motivation is higher or more likely lower than stated. Therefore, it has to be reconsidered to integrate a certain error for the initial motivation values. We solved this problem by distributing the motivation randomly within numeric boundaries. Another solution might be the definition of a fuzzy set for modelling the initial motivation.

By way of conclusion it should be pointed out again that due to that subjectivity and the limited sample size, some of the results can only provide a vague indication on the underlying interrelationships. Nevertheless, this simulation study gave us the opportunity for successfully testing and improving hybrid tokens and the associated computational methods. More detailed data might also enable us to model more than one continuous attribute in the hybrid token influencing each other, e.g. the mood of a patient having an influence on the compliance, as well as discrete events occurring during the therapy. Only those complex interrelationships will be able to take real advantage of the hybrid token approach.

Eventually, all results have to be reviewed again and above all have to be discussed with physicians and psychotherapist for explaining the observed effects. When a suitable amount of proper data is available, the study will be resumed, especially focussing on the course of the compliance during the therapy and the sequence of treatments. In the face of restrictions and simplifications, we believe that a model like this enables the estimation of the therapeutic outcome and, after a comprehensive data analysis, might provide a decision support for physicians and psychotherapists.

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