Identifying Emotion Regulation Altering Targets as Depressive Mood Disorder Treatments Using Fuzzy Stochastic Hybrid Petri Nets

Mani Mehraei
Eastern Mediterranean University, Turkey

Abstract

Recent studies support that emotion regulation plays a prominent role in depression and depressive mood related disorders. However, the details related to such relations are still unknown. Therefore, constructing a model to describe and analyze these connections is essential. Fortunately, there exist many strategies to treat depressive mood disorders, but choosing the correct strategy for any individual should be personalized. Thus, there are always alternatives for discovering novel strategies to improve the treatments. The aim of this study is to model the relation between emotion regulation and depression to identify emotion regulation altering targets to improve the treatment of depressive mood disorders. By random sampling method, 108 volunteers were selected from Eastern Mediterranean University. The significant emotion traits, emotion interaction probability distribution, and personality traits of these individuals were measured using a questionnaire. In the present study, Fuzzy Stochastic Hybrid Petri nets were used as a mathematical tool to model this complex psychological system. Fuzzy and stochastic properties made it possible to deal with randomness feature of psychological systems and unknown kinetic parameters, respectively. The simulation results were obtained by finding the mean of 40,000 stochastic runs with 95% confidence level. The simulation results validated that decreasing the level of anger, distress, and fear may decrease the severity of depression. In addition, the comparison of these simulation results revealed that decreasing the level of shame, and increasing the sense of gratification can be considered to be emotion regulation altering targets, and thus as potential psychotherapy of depressive mood disorders.

Keywords: depressive mood disorders, emotion regulation, fuzzy stochastic petri nets, quantitative modeling

Introduction

Depression is a common disorder that negatively affects feelings, actions, and the way of thinking of an individual (American Psychiatric Association, 2013). The prevalence of major depressive disorder together with bipolar depression (major depressive episode) in a lifetime is about 53% based on the World Mental Health surveys (WMH) (Kessler & Bromet, 2013). Fortunately, there exist several treatments for depression such as drug therapy, psychotherapy, and electroconvulsive therapy (ECT) (American Psychiatric Association, 2013). However, diagnosis and treatment process of depression should be personalized since there are genetics, personality, and environmental factors to be considered. On the other hand, one of the obvious symptoms of either mild or major depression is having sad emotional responses and depressive mood. Therefore, emotion regulation as a collection of regularity processes which controls the behavior of our affective responses (Gross & Thompson, 2007) can be considered as a target for treating depressive mood disorders.

The role of emotion traits such as anger, fear, distress, and shame in depression is inevitable as it is discussed in many recent studies (Joormann & Vanderlind, 2014; Mohammadkhani et al., 2016; Michopoulos et al., 2015; Yoon et al., 2013). Many empirical studies revealed that there exist consistent links between anger and depression (Balsamo, 2013). A regression analysis of data obtained from a survey in region of Korea showed that anger plays a prominent role in suicidal ideation beyond the effect of depression (Jang et al., 2014). Therefore, anger can be a component to consider in studies related to emotional regulation to treat depression. On the other hand, when it comes to changing the level of fear in an individual, there are emotional regulation techniques such as extinction, cognitive emotion, active coping, and reconsolidation to treat psychological disorders such as depression (Hartley & Phelps, 2010). Distress is the other component, which should be under consideration. The result of comparing compulsory and voluntary admissions of patients with substance use disorders revealed that distress has played a vivid role in depression too (Pasareanu, 2017). Thus, there must be an approach to compare such emotional regulation techniques with each other, and predict novel strategies to ideally treat depression.

It is essential to find a model to explain how objects, agents, and events are appraised based on personalities of individuals to identify possible emotion regulation altering targets to treat depressive mood disorders. Ortony, Clore, and Collins (OCC) introduced such a model in the early 90s (Ortony et al., 1990). A few years after that, Mehrabian constructed a model to describe mood states based on three independent components – Pleasure, Arousal, and Dominance (PAD) (Mehrabian, 1996). Then, a mapping from OCC emotions to PAD mood components was introduced in Alma's approach to establish a link between the mentioned models (Gebhard, 2005). Finally, models were constructed to predict emotion and mood states by using time series forecasting methods (Mehraei & Akcay, 2017) and stochastic petri nets (Mehraei, 2017).

The current study aims to identify emotion regulation altering targets by extending the model introduced by Mehraei (Mehraei, 2017) to find potential psychotherapies for depressive mood disorders. The extended model includes fuzzy parameters to deal with unknown or missing process rates in the model.

Methods

Petri nets

A classical Petri net is a directed graph consisting of places, transitions, and arcs (Murata, 1989). A pair of place and transition can be connected by a directed arc, but there cannot be an arc connecting any two places/transitions to each other. Arcs are identified by their weights, indicating the number of parallel arcs between specified pair of objects. Dynamic structure of a Petri net can be described in terms of flow of tokens. The distribution of tokens among places in a Petri net is called marking.

When the size of a marking grows exponentially, it rises a problem named state explosion problem. State explosion problem is the main drawback of analyzing dynamic discrete event systems with classical Petri nets (Recalde et al., 2007). Continuous Petri nets were introduced by defining continuous places and transition to avoid state explosion problem (David & Alla, 1987). Hybrid Petri nets can be used in systems, which both discrete and continuous places/transitions must be defined (David & Alla, 2001). Extensions such as time, color, stochastic, and fuzzy have been added to Petri nets to model complex biological systems over the past two decades (Liu & Heiner, 2016). In the field of experimental psychology, stochastic Petri nets has been used to predict mood states (Mehraei, 2017).

Creating the model

The sample in this study comprised 108 students or employees at Eastern Mediterranean University after removing the volunteers with missing data and outliers. More than 52% of these participants were female, and the average age of the total sample size was 24 with standard deviation of 3.2 years. These volunteers were born in various countries, so they came from diverse backgrounds. To increase the reliability of the obtained data, the volunteers were asked to fill the questionnaire anonymously. The questionnaire was designed to obtain the following: 1) measuring the main personality traits, which are Openness, Conscientiousness, Extraversion, Agreeableness, Neuroticism (Mehrabian, 1996); 2) The probability distribution of the most significant emotion state before and after a certain event (Mehraei, 2017); and 3) The most significant emotion hour by hour for two weeks (Mehraei & Akcay, 2016; Mehraei, 2017).

The extended model in this study was conducted based on quantitative modeling with fuzzy stochastic Petri nets on the Snoopy platform (Heiner et al., 2012). New places, transitions, arcs, and properties were added to the initial model (Mehraei, 2017). The initial model contained 20 continuous places; 17 of these continuous places represented the possible emotion states which are anger, admiration, dislike, disappointment, sadness, fear, gloating, hate, hope, joy, like, love, pity, pride, relief, resentment, and shame. The other two continuous places showed the concentration level of PAD independent mood components. 6 discrete places were added to the extended model. Absence of a token in 4 of these discrete places caused 50% decrease in concentration level of a certain emotion state. On the other hand, the presence of a token in the other two discrete places lead to depressive mood or increase in sense of gratification. The initial model contained 48 stochastic transitions to transfer a certain emotional state to another one. The extended model had 4 additional stochastic transitions to decrease the level of certain emotion types by 50%. There were 35 continuous transitions in the initial model to update mood states based on changes in emotional states by using the mapping in Alma's approach (Gebhard, 2005). There were 4 additional continuous transitions in the extended model to decrease or increase the level of PAD mood components in case of depression or increase in sense of gratification, respectively. There exist 460 regular arcs to connect places to transitions and vice versa, and 8 inhibitory arcs in the extended model. To obtain reliable information from simulation results, accurate parameters should be defined in a stochastic Petri nets model. However, many kinetic parameters in psychological systems are uncertain, vague, or unknown. On the other hand, these kinetic parameters are different in individuals. Fuzzy stochastic Petri nets (FSPNs) were introduced to solve this problem by combining stochastic Petri nets and fuzzy sets (Liu & Heiner, 2016). In such FSPNs, fuzzy numbers can be considered as the kinetic parameters instead of crisp real values (Lue & Heiner, 2016). Therefore, in the proposed extended model, fuzzy stochastic hybrid Petri nets was applied to cover randomness and fuzziness of psychological systems by considering both continuous and discrete components.

The structure of the extended model is the same for all individuals, but the initial markings and process rates should be personalized. In this study, the initial markings and process rates were defined based on the sample. For instance, the relative frequency of changing a specific emotional state to another one was different in each person. Thus, the rates for the stochastic transitions of the extended model were calculated by using emotion interaction probability distribution for each person. The reason such transitions were set to stochastic type is to consider the randomness of the events. A part of such segments in the model is illustrated in Figure 1.

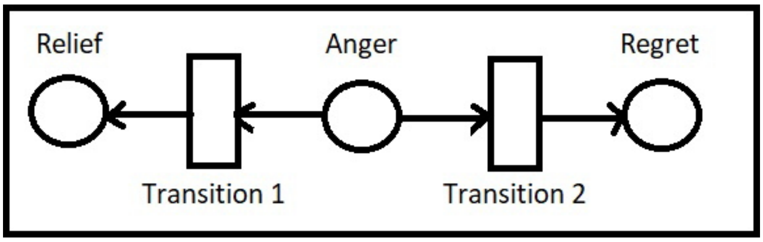

Figure 1: A part of emotion interactions in the extended model.

PAD mood components were defined as continuous places. Their possible values could be any real number from -1 to 1. Since markings in Petri nets cannot take negative numbers, a mapping was applied to assign -1 to minimum value, and 1 to maximum value, respectively. The initial markings for PAD mood components places were set to the calculated values of the mapping from OCEAN personality traits (Mehrabian 1996; Gebhard, 2005), which were obtained from the questionnaire.

PAD mood components can be updated by using a function defined by the history of emotion and mood states in an individual as its domain (Mehrabian, 1996; Gebhard, 2005; Mehraei & Akcay, 2016). The transitions in the extended model were defined as continuous transitions to constantly update PAD mood components. The process rates for these continuous transitions are assigned by applying Alma's mapping from OCC emotions to PAD mood space (Gebhard, 2005), and such process rates are fixed for all individuals regardless of their personalities as an estimation. For example, if someone feels fear type of emotion, it is expected that fear emotion state negatively affects pleasure and dominance mood components, and positively influences arousal mood component. This example is illustrated in Figure 2.

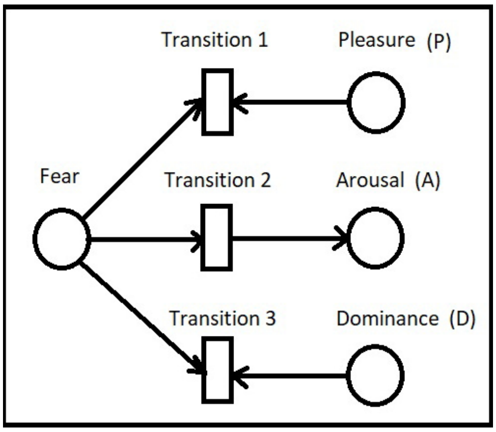

Figure 2: A part mood updating in the extended model.

Depression as a discrete place in the fuzzy stochastic hybrid Petri nets model was defined the way to decrease the level of PAD mood components by using inhibitory arcs. Whenever there was no token in this place, a continuous transition was activated and affected PAD mood components negatively. On the other hand, experiencing a sense of gratification was defined as a discrete place to increase the level of PAD mood components by 3 inhibitory arcs using Alma's mapping (Gebhard, 2005). These components are illustrated in Figure 3.

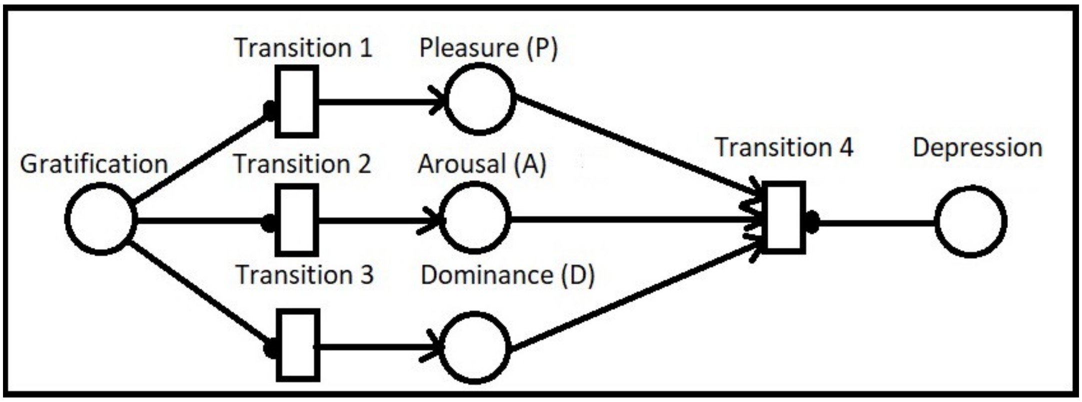

Figure 3: Gratification and Depression discrete places in the extended model.

There are few stochastic transitions in the extended model to decrease the level of specific emotional states by 50%. These transitions randomly change a specific emotion to another emotion type, and their process rates are personalized for each person. To activate such transitions, discrete places with corresponding inhibitory arcs were defined. An example of such segments in the model is illustrated in Figure 4. In the extended model, the initial markings were defined as fuzzy numbers instead of crisp values to cover the problem regarding to unknown, missing, or uncertain values.

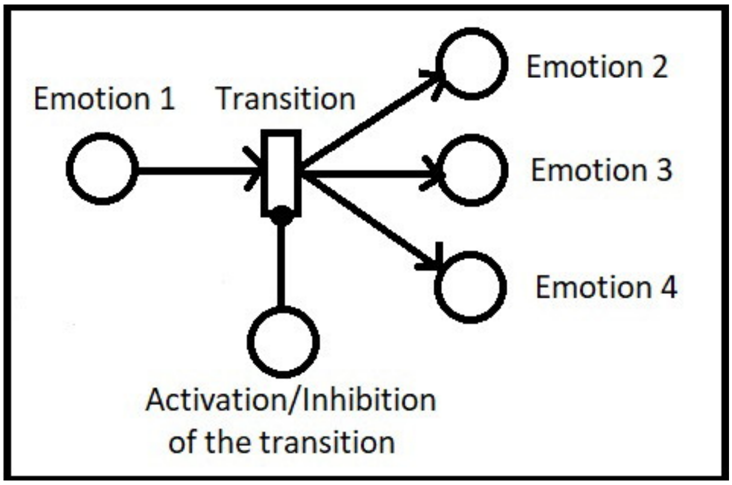

Figure 4: An example of decreasing the level of specific emotions.

Results and Discussion

It was validated that stochastic Petri nets can model PAD mood components accurately (Mehraei, 2017). The extended model as a fuzzy stochastic Petri nets was conducted on Snoopy platform (Heiner et al., 2012) with the same sample in the previous study (Mehraei, 2017). The simulation results were found by calculating the average point of 40,000 stochastic runs with 95% confidence level based on the formula proposed by Sandmann and Maier (Sandmann & Maier, 2008). Such a large number of runs was considered to obtain a coefficient of variation close to 1, and not to neglect the accuracy (Liu et al., 2016). The ending point of the time interval was set on 500 to compare simulation results with each other at a certain Petri Time (Pt).

As explained earlier, Petri net markings do not accept negative values. Therefore, there is a mapping from the simulation results to PAD components, which should take values between -1 to 1. The mean of the simulation results for each PAD components can be considered as the value 0. Thus, when a mood component value was bigger than the mean, it was considered a positive value, otherwise a negative value. It is known that in the case of a depressive mood, all PAD components are negative (Mehrabian, 1996).

Anger, distress, and fear emotion levels were intentionally decreased by 50% one by one to make it possible to quantitatively compare their influences on PAD components as illustrated in Figure 4. The simulation result shows that decreasing the level of anger emotion leads to positive Pleasure and Dominance components, but the Arousal component remains negative. On the other hand, the simulation results reveal that all PAD components remain negative. The simulation results related to decreasing the level of fear component was similar to anger emotion. However, the level of increase or decrease in PAD components were not exactly same. The calculated average of the markings showed that decreasing the level of anger, distress, and fear emotions increased the level of the Pleasure component by 3.3, 1.5, and 3.1 folds, Arousal component by 1.4, 1.2, and 1.2 folds, and Dominance component by 1.8, 1.5, and 1.6 folds, respectively. These simulation results are in line with the mapping used in Alma's approach (Gebhart, 2005).

The proposed model made it possible to manipulate emotion types and predict the possible mood states based on PAD components. The level of emotion types was decreased intentionally by 50% to check which emotion type can positively affect PAD components the most.

Surprisingly, decreasing the level of shame emotion along with experiencing sense of gratification led to the biggest number of folds in all PAD components. This proposed strategy increased the level of Pleasure, Arousal, and Dominance components by 3.3, 1.8, and 1.9, respectively. The summary of these results is illustrated in Figures 5.

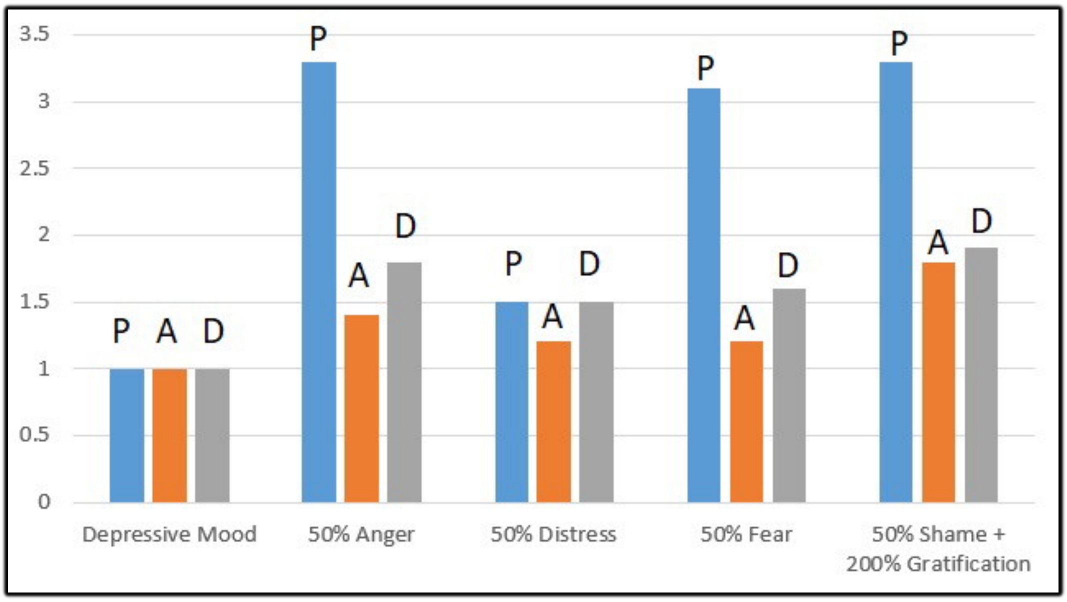

Figure 5: Simulation results of Pleasure (P), Arousal (A), and Dominance (D) components.

Conclusion

This study showed that fuzzy stochastic hybrid Petri nets is a proper mathematical tool to model and analyze psychological systems such as depressive mood disorder pathways. The simulation results validated the mapping from emotion types to PAD components, which had been used in Alma's approach (Gebhart, 2005). Decreasing the levels of anger, distress, and fear emotions were helpful for lifting mood states, but it was not good enough to keep all PAD mood components positive. For example, decreasing the anger emotion's level increased pleasure and dominance component, but could not increase arousal component significantly. In the proposed strategy, decreasing shame emotion along with increasing sense of gratification made all PAD components positive significantly with p-value less than 0.05. Therefore, shame and gratification can be potential emotion regulation altering targets to treat depressive mood disorders. This strategy can be used as psychotherapy, without using drugs and facing their possible side effects.

Clearly, there are many factors which affect PAD components. To include all the factors in the model was out of the scope of this study. However, considering fuzzy parameters and stochastic processes made it possible to neglect factors such as environmental factors.

In future studies, the proposed model can be extended to find novel treatments for depressive mood disorders, and eventually depression itself. Other factors can be integrated in the model, and their roles can be discussed accurately. Such a mathematical modeling helps us to shed light on the way psychological systems work, and find potential treatments for various psychological disorders before trying to run experiments on patients.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders*. (5th ed.). Alington, VA: American Psychiatric Publishing.

Balsamo, M. (2013). Personality and depression: Evidence of a possible mediating role for anger trait in the relationship between cooperativeness and depression. *Comprehensive psychiatry*, *54*(1), 46–52. https://doi.org/10.1016/j.comppsych.2012.05.007

David, R., & Alla, H. (1987). Continuous Petri nets. Paper presented at the 8th European Workshop on Application and Theory of Petri nets.

David, R., & Alla, H. (2001). On hybrid Petri nets. *Discrete Event Dynamic Systems, 11*(1–2), 9–40.

Gebhard, P. (2005). Alma: a layered model of affect. *In Proceedings of the fourth international joint conference on Autonomous agents and multiagent system,* 29–36.

Gross, J. J., & Thompson, R. A. (2007). Emotion regulation: Conceptual foundations. In J. J. Gross (Ed.), *Handbook of Emotion Regulation* (pp.3–24). New York: Guilford Press.

Hartley, C. A., & Phelps, E. A. (2010). Changing fear: the neurocircuitry of emotion regulation. *Neuropsychopharmacology, 35*(1), 136. https://doi.org/10.1038/npp.2009.121

Heiner, M., Herajy M., Liu F., & Schwarick, M. (2012, June). Snoopy – a unifying Petri net tool, *In Proceedings of Petri nets 2012, LNCS, 7347*, 398–407, Hamburg, Germany.

Jang, J. M., Park, J. I., Oh, K. Y., & et al. (2014). Predictors of suicidal ideation in a community sample: roles of anger, self-esteem, and depression. *Psychiatry research*, *216*(1), 74–81. https://doi.org/10.1016/j.psychres.2013.12.054

Joormann, J., & Vanderlind, W. M. (2014). Emotion regulation in depression the role of biased cognition and reduced cognitive control. *Clinical Psychological Science*, *2*(4), 402–421. https://doi.org/10.1177/2167702614536163

Kessler, R. C., & Bromet, E. J. (2013). The epidemiology of depression across cultures. *Annual review of public health*, *34*, 119–138. https://doi.org/10.1146/annurev-publhealth-031912-114409

Liu. F., & Heiner, M. (2016). Fuzzy stochastic Petri sets for modeling biological systems with uncertain kinetic parameters, *PLoS one 11*(2), e0149674. https://doi.org/10.1371/journal.pone.0149674

Mehrabian, A. (1996). Pleasure-arousal-dominance: A general framework for describing and measuring individual differences in Temperament, *Current Psychology*, *14*(4), 261–292. https://doi.org/10.1007/BF02686918

Mehraei, M., & Akcay, N. I. (2016). Mood and emotional states prediction by time series methods, *International Psychological Applications Conference and Trends 2016 (INPACT2016),* Pracana, C., & Wang, M. (eds), Lisbon, Portugal, 382–386.

Mehraei, M., & Akcay, N. I. (2017). Pleasure, Arousal, and Dominance Mood Traits Prediction Using Time Series Methods, *IAFOR Journal of Psychology and the Behavioral Sciences, 3*(1), https://doi.org/10.22492/ijpbs.3.1.01

Mehraei, M. (2017). Mood States Prediction by Stochastic Petri Nets, *International Psychological Applications Conference and Trends 2017 (INPACT2017),* Pracana, C., & Wang, M. (eds), Budapest, Hungary, 258–262.

Michopoulos, V., Powers, A., Moore, C., Villarreal, S., Ressler, K. J., & Bradley, B. (2015). The mediating role of emotion dysregulation and depression on the relationship between childhood trauma exposure and emotional eating. *Appetite*, *91*, 129–136. https://doi.org/10.1016/j.appet.2015.03.036

Mohammadkhani, P., Abasi, I., Pourshahbaz, A., Mohammadi, A., & Fatehi, M. (2016). The Role of Neuroticism and Experiential Avoidance in Predicting Anxiety and Depression Symptoms: Mediating Effect of Emotion Regulation. *Iranian journal of psychiatry and behavioral sciences*, *10*(3). https://doi.org/10.17795/ijpbs-5047

Murata, T. (1989). Petri nets: Properties, analysis and applications. *proceedings of the IEEE, 77*(4), 541–80.

Ortony, A., Clore, G. L., & Collins, A. (1990). The cognitive structure of emotions. Cambridge University Press.

Pasareanu, A. R., Vederhus, J. K., Opsal, A., Kristensen, Ø., & Clausen, T. (2017). Mental distress following inpatient substance use treatment, modified by substance use; comparing voluntary and compulsory admissions. *BMC Health Services Research*, *17*(1), 5. https://doi.org/10.1186/s12913-016-1936-y

Recalde, L., Haddad, S., & Silva, M. (2007). Continuous Petri nets: expressive power and decidability issues. *Automated Technology for Verification and Analysis*. 362–377. Springer Berlin Heidelberg.

Sandmann, W., & Maier, C. (2008). On the statistical accuracy of stochastic simulation algorithms implemented in Dizzy, *Proc. WCSB, 2008*, 153–156.

Yoon, K. L., Maltby, J., & Joormann, J. (2013). A pathway from neuroticism to depression: examining the role of emotion regulation. *Anxiety, stress & coping*, *26*(5), 558–572. https://doi.org/10.1080/10615806.2012.734810

Corresponding Author: Mani Mehraei
Email: mani.mehraei@emu.edu.tr