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Exploring the dynamics of providing cognition using a computational model of cognitive insomnia

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ABSTRACT

Insomnia is a common sleep-related neuropsychological disorder that can lead to a range of problems, including cognitive deficits, emotional distress, negative thoughts, and a sense of insufficient sleep. This study proposes a providing computational dynamic cognitive model (PCDCM) insight into providing cognitive mechanisms of insomnia and consequent cognitive deficits. Since the support providing is significantly dynamic and it includes substantial changes as demanding condition happen. From this perspective the underlying model covers integrating of both coping strategies, provision preferences and adaptation concepts. The model was found to produce realistic behavior that could clarify conditions for providing support to handle insomnia individuals, which was done by employing simulation experiments under various negative events, personality resources, altruistic attitude and personality attributes. Simulation results show that, a person with bonadaptation and either problem focused or emotion focused coping can provide different social support based on his personality resources, personality attributes, and knowledge level, whereas a person with maladaptation regardless the coping strategies cannot provide any type of social support. Moreover, person with close tie tends to provide instrumental, emotional, and companionship support than from weak tie. Finally, a mathematical analysis was used to examine the possible equilibria of the model.

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1. INTRODUCTION

Insomnia is a condition where a person experiences poor quality sleep, difficulty falling and staying asleep, waking up during the night, or waking up earlier than intended [1]. These symptoms can result in daytime problems such as decreased cognitive function, decreased productivity, fatigue, depression, irritability, impaired decision-making, low motivation, and mood changes [2]. Researchers have become interested in the cognitive-vulnerability models, which explain how insomnia can lead to mood dysregulation and cognitive deficiencies [3]. If insomnia is the primary concern, a vicious cycle of insomnia-anxiety-insomnia can emerge, leading to affective dysregulation, impulsivity, restlessness, excessive daytime sleepiness, decreased vigilance, and cognitive decline over time [4].

There are various theoretical and cognitive-computational models related to insomnia, including the cognitive vulnerability model for insomnia induced mood disturbances (CVMIMD), the sleep-specific cognitive vulnerability (SSCV), the behaviorally induced insufficient sleep syndrome with restricted and extended sleep opportunity (BIISS-RESO), and the global cognitive vulnerability to insomnia (GCVI) [5], [6]. This paper focuses on the development of a computational model to understand how social support networks (SSNs) can aid in providing effective support to individuals suffering from insomnia. The paper delves into various cognitive and theoretical models related to insomnia, including CVMIMD and the BIISS-RESO.

In the field of intelligence analysis, there is a growing interest in understanding how cognitive capabilities are affected by collaborative models in order to generate high-quality plans, make effective decisions, and develop shared awareness of insomnia [7], [8]. Two approaches have been used to study this: social psychological research, which focuses on small groups of humans observed in a task context, and computer simulation techniques, which can explore 'what-if' scenarios and manipulate variables that are difficult to control in real-world situations [9], [10]. However, there are limitations to both approaches. Social psychological research is limited to small groups with simple communication structures and tasks that may not generalize to real-world situations, while computer simulations often lack psychologically-realistic cognitive processing capabilities [11], [12]. Some researchers argue for the use of socio-cognitive simulations to address these limitations.

Various factors can motivate individuals who provide social support when faced with the task of assisting someone with insomnia [13], [14]. It can be a challenging experience for family members, spouses, or friends who are offering support to someone with this condition [15], [16]. The cognitive motivational relational theory by Lazarus and Folkman suggests that the way providers appraise the situation of insomnia can determine whether they cope with anxiety by attempting to change the situation (problem-focused) or by addressing the emotional consequences of the events (emotion-focused) [17], [18]. Although most providers handle the task of helping someone with insomnia well, there are some who struggle [18], [19].

Numerous research studies explore the adverse effects that insomnia can have on individuals, including emotional exhaustion, burden, and maladaptation [18], [19]. Providing support to someone with insomnia is a highly dynamic process, and it requires significant resources to monitor effectively in real-world settings. Each provider has various cognitive and physiological mechanisms that regulate how insomnia impacts their health and well-being [19], [20]. While much effort has been devoted to understanding the behavioral mechanisms of providing support, there has been limited attention given to a computational modeling perspective on how providers can assist individuals with insomnia [20], [21].

In the current paper, we describe a computational model of insomnia cognition that is grounded in an extensive body of work in the psychological literature. The model features the use of SSNs to model one particular form of providing cognition, namely coping process, adaptation concepts, and support preferences, as this has become one of the fundamental components for building a provider model that can give social support of individuals with different condition during demanding events. The primary contribution of this paper is the novel insight it provides into the role of SSNs in the context of insomnia. This is significant because existing research predominantly focuses on the cognitive and behavioral aspects of insomnia without integrating a computational perspective on social support. By introducing a computational model grounded in psychological literature, this study addresses the gap in understanding how providers' cognitive and physiological mechanisms interact when supporting someone with insomnia. This research not only enhances the theoretical framework around insomnia and social support but also has practical implications for designing interventions that can better assist individuals dealing with insomnia. The major issue addressed here is the lack of comprehensive models that incorporate socio-cognitive simulations to realistically depict cognitive processing in support scenarios, bridging the gap between theoretical research and real-world applications.

By the end of the introduction, readers will understand that this paper offers a computational approach to studying insomnia and social support, why this approach is valuable, and how the argument will be developed through the subsequent sections. The section 2 presents the essential principles of insomnia provision behavior throughout demanding events. From this standpoint, the formulation and design of a formal model is developed in section 3. In section 4, simulation traces are shown to demonstrate how this model meets the expected outcomes in social network ties. Section 5 presents a detailed mathematical analysis to evaluate the correctness of the proposed model. Finally, section 6 concludes this paper.

2. THE COMPREHENSIVE THEORETICAL BASIS ON COGNITIVE VULNERABILITY MODEL FOR INSOMNIA

From a neurocognitive perspective, the pre frontal cortex (PFC), which is responsible for regulating emotions and cognitive functions, undergoes significant development during neurodevelopment and adolescence due to neuroplasticity. When hypnic tone is reduced due to poor sleep habits or socio-behavioral and psychophysiological stressors, the activation of maladaptive processes in the PFC is proposed as a potential

neurocognitive mechanism underlying the affective consequences of insomnia and inefficient sleep in general, according to [20], [21]. The body of psycho-behavioral and neurocognitive research that explains the exact mechanisms that link insomnia and negative mood is limited. However, subjective experiences of sleep insufficiency and dysregulated mood have a stronger association than objective findings from polysomnography or sleep electroencephalography data [22]. This suggests that psychological factors that interfere with sleep efficiency may play significant roles in explaining the relationship between sleep and mood [23]. Some of these cognitive vulnerability factors associated with insomnia are now recognized as mistaken beliefs, cognitive biases, and thought patterns that increase the likelihood of individuals developing psychopathology.

2.1. Sleep specific cognitive vulnerability

In some cases, mistaken beliefs and attitudes are specifically related to sleep problems. In such cases, the dysfunctional beliefs and attitudes about sleep (DBAS) scale is used to assess the distressing worries related to insomnia. Harvey's cognitive model explains how these dysfunctional beliefs and attitudes can affect insomnia complaints. According to this model, insomniacs often worry about poor sleep and its consequences during the day. These negative thoughts can trigger a bias towards monitoring sleep-related threat cues, which leads to over-monitoring of these cues. Previous studies have shown a strong link between DBAS and poor sleep, which plays a significant role in disturbances in sleep perception and sleep safety behaviors such as napping, according to Harvey's model [23].

2.2. Behaviorally induced insufficient sleep syndrome with restricted and extended sleep opportunity

Patients commonly complain of difficulty sleeping at night and difficulty waking up in the morning, which is referred to as a specific condition [24]. People with initial or maintenance insomnia tend to have shorter habitual sleep episodes than the norm for their age group, as confirmed by their medical history, sleep log, or actigraphy. These patients often experience sleep inertia in the morning and excessive daytime sleepiness for at least three months before seeking medical help [25]. However, they tend to sleep for longer periods on weekends or during vacations. Objective measurements of sleep efficiency using polysomnography indicate that it is generally below 80%, and the mean time it takes to fall asleep at night is longer than 45 minutes. Additionally, patients report experiencing repeated awakenings during the night.

2.3. Global cognitive vulnerability to insomnia

Global cognitive vulnerability is characterized by dysfunctional beliefs and attitudes that are not specific to any particular behavior or experience. According to Beck's cognitive model, negative attitudes and biases towards oneself, the world, and the future can develop from early life traumas and complicated past experiences, resulting in maladaptive schemas that trigger cognitive vulnerabilities and negative tendencies, leading to depression later in life. Several studies have found strong links between sleep problems, particularly insomnia, and negatively toned cognitive constructs associated with anxiety, depression, and hopelessness. Personalized treatment approaches are necessary to address the various types of insomnia, which include adjustment, drug-induced, comorbid, onset, middle, late, conditioned, behavioral, idiopathic, paradoxical, and sleep hygiene insomnia. Insomnia patients can be categorized into neutral or clinical types based on the severity of their sleep difficulties. Gross's model of emotion explains how emotions are generated and evolve over time through a process that involves attention, appraisals, multi-faceted emotional responses, and feedback to modulate the current situation continually [26].

The model shows how emotions are dynamic and suggests strategies for regulating them, such as situation selection, modification, attention deployment, cognitive change, and response modulation. Previous studies mentioned in the text lacked discussion on causal relationships, which may lead to misinterpretation of findings. Thus, there is a need for a new approach to conceptualize theories and hypotheses to draw data models for testing mediating relationships between independent variables and outcomes in retrospective studies and to suggest research strategies for prospective studies on insomnia. This study aims to address this gap in the literature by proposing and validating a novel computational cognitive model for insomnia based on previous models. The computational cognitive model explains how cognitive processes and interactions can cause annoyance and distress reactions, leading to the development or maintenance of insomnia. The study also demonstrates the insomnia numerical model through multi-mediatory (causality) modeling approaches.

3. METHOD

A computational cognitive model is used as techniques in this paper. Thus, in cognitive science, models can generally be categorized into three types: computational, mathematical, and verbal-conceptual. Computational models use algorithmic descriptions to detail processes. Mathematical models employ

mathematical equations to depict relationships between variables. Verbal-conceptual models describe entities, relationships, and processes using natural language. Regardless of the type, each model can be seen as a theory explaining the phenomena it aims to represent.

While all these model types have their roles, this paper primarily focuses on computational modeling, particularly those based on computational cognitive architectures. This emphasis is due to the current promise of computational modeling, which offers unmatched flexibility and expressive power. It provides various modeling techniques and methodologies and supports practical applications of cognitive theories. Mathematical models are often considered a subset of computational models since they can usually be implemented computationally. Computational models are mainly process-based theories, focusing on how human performance occurs, the psychological mechanisms and processes involved, and the specific ways in which these operate. It is also possible to develop theories of the same phenomena through "product theories," which provide a precise functional account without committing to specific psychological mechanisms or processes. A providing computational dynamic cognitive for insomnia (PCDCI) model was evolved from [27] model, as mentioned in the previous section (analysis of cognitive dynamics in appraisal and coping strategy), computational properties for the provision insomnia model can be specified. These computational properties are illustrated to simulate the individual's reaction in coping when exposed to the depression, as well as the possible consequences of that action as shown in Figure 1.

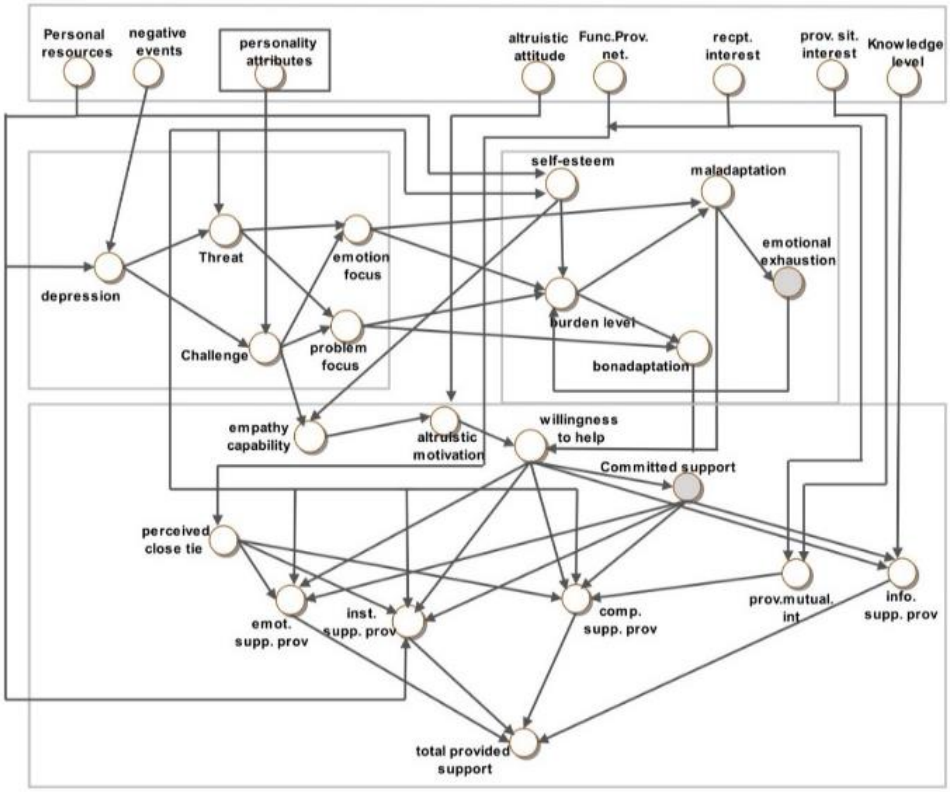


Figure 1. Variables and its relationships that involved in the providing modeling for insomina

3.1. Depression

The depression (de) denotes the degree of stress experienced by a person based on negative events (Nv) and his or her personal resources (Pr), which is controlled by the proportion factor (η_i).

$$de(t) = \eta_i . Nv(t) + (1 - \eta_i) . (Nv(t)) . (1 - Pr(t)) \quad (1)$$

3.2. Challenge and threat

Challenge (Ch) is positively related with personality attributes (Pa), while negatively with the intensity of stress through the proportional factor (β_c).

$$Th(t) = (Ie(t) . (1 - Pa(t)) \quad (2)$$

$$Ch(t) = \beta_c . Pa(t) + (1 - \beta_c) . Pa(t) . (1 - Ie(t)) \quad (3)$$

3.3. Problem and emotional-focused coping

The presence of threat generates emotional-focused coping (Ef) level, whereas the presence of challenge generates problem-focused coping (Pf), which delivers a positive effect.

$$Ef(t) = Th(t) . (1 - Ch(t)) \quad (4)$$

$$Pf(t) = Ch(t) . (1 - Th(t)) \quad (5)$$

3.4. Burden level and self–esteem

A combination of personal resources (Pr) and personality attributes (Pa) triggers the self-esteem (Sf) through proportional contribution (α_s). Self-esteem (Sf), and second proportional contribution (σ_b) between emotion-focused coping (Ef) and long-term emotional exhaustion (Eh).

$$Sf(t) = \alpha_s Pr(t) + (1 - \alpha_s) . Pa(t) \quad (6)$$

$$Bl(t) = (1 - [\gamma_b . Pf \rightleftarrows (t) + (1 - \gamma_b) . (Sf(t)]) . (\sigma_b . Eh(t) + (1 - \sigma_b) . Ef(t)) \quad (7)$$

3.5. Maladaptation, bonadaptation, and emotional exhaustion

The maladaptation (Ma) is calculated using the combination of burden level and emotional-focused coping. In the case of bonadaptation, it is determined by measuring the burden level and problem-focused coping. Parameters ω_m and η_b, provide a proportional contribution factor in respective relationships.

$$Ma(t) = \omega_m . Ef(t) + (1 - \omega_m) . Bl(t) \quad (8)$$

$$Ba(t) = \eta_b . Pf(t) + (1 - \eta_b) . (1 - Bl(t)) \quad (9)$$

$$Eh(t + \Delta t) = Eh(t) + \psi_e . [(Ma(t) - Eh(t)) . (1 - Eh(t)) . Eh(t)] . \Delta t \quad (10)$$

3.6. Empathy capability, altrustic motivation, and willingness to help

The presence of both positive personality (Pa) attributes and self-esteem (Sf) trigger the empathy capability (Ec) through a proportional factor (λ_e). A combination of altruistic attitude (Al) and empathy capability (Ec) determine the level of the altruistic motivation (Am) by a proportional factor (β_m).

$$Ec(t) = \lambda_e . Pa(t) + (1 - \lambda_e) . (Sf(t)) \quad (11)$$

$$Am(t) = \beta_m . Al(t) + (1 - \beta_m) . (Ec(t)) \quad (12)$$

$$Wh(t) = \lambda_w . Ba(t) + (1 - \lambda_w) . [1 - (1 - Am(t)) . Ma(t)] \quad (13)$$

3.7. Support provision preference (informational, instrumental, emotional, and companionship)

All support provision preferences require willingness to help (Wh) in the proposed model, and with its additional attributes.

$$Ip(t) = (Wi_1 . Kl(t) + Wi_2 Cm(t)) . Wh(t) \quad (14)$$

$$Ep(t) = Wh(t) . [\psi_e Cm(t) + (1 - \psi_e) . (We_1 . Ag(t) + We_2 . Pc(t))] \quad (15)$$

$$Np(t) = Wh(t) . [\tau_n Cm(t) + (1 - \psi_e) . (Wn_1 . Ag(t) + Wn_2 . Pc(t) + Wn_3 Pr(t))] \quad (16)$$

$$Mi_{a,b}(t) = \sum sim(Ri(t), Ps(t))/nm \quad (17)$$

$$Cp(t) = Wh(t) . [\mu_c Cm(t) + (1 - \mu_c) . (Wc_1 . Ev(t) + Wc_2 . Pc(t) + Wc_3 . Mi_{a,b}(t))] \quad (18)$$

3.8. Committed support and total of provision support

The long-term concept committed support (Cm) can be employed to measure willingness to help (Wh) by flexibility rates (σ_c). The total of support related to n_s number of supports is called total provided support (Ts).

$$Cm(t+\Delta t) = Cm(t) + \sigma_c \,.\, [(Wh \rightleftarrows (t) - Cm(t)).(1 - Cm(t)).Cm(t)].\Delta t \quad (19)$$

$$Ts(t) = (Ip(t) + Np(t) + Ep(t) + Cp(t))/\sum n_s \quad (20)$$

4. RESULTS AND DISCUSSION

Many simulations have been performed to discover interesting patterns among insomnia provider's support tie preference behaviors. Some anticipated patterns can be discovered with variations in individual and inter-personal attributes. This paper deals with three fictional individual conditions as shown in Table 1 exposed to different set of initial attributes. Table 1 summarizes the values of these profiles.

Based on this, there are five provision scenarios for Insomnia are presented: an individual likely to provide informational support (A), an individual likely to provide emotional support (B), an individual likely to provide instrumental support (C), an individual likely to provide companionship support (D), and an individual is not providing any support (E). The duration of our simulation was initialized at 1,000 time points under these flexibility and proportional settings; Δt=0.2,γ_b=η_i=β_c=α_s=σ_b=ω_m=$\rightleftarrows$ ψ $\rightleftarrows_s$=λ_e=σ_c=λ_w=0.5. For this simulation, these individuals experience high negative events throughout the simulation time. Several systematic experiments were conducted to obtain the most appropriate parameter settings for this model as summarized in Table 2.

Table 1. Individuals profiles

Provider support preference individuals	Profiles								
	Pr	Nv	Al	Pm	Pc	Kl	Pa	Ag	Ev
A	0.3	0.2	0.9	0.3	0.2	0.9	0.9	0.1	0.2
B	0.1	0.9	0.9	0.2	0.9	0.1	0.9	0.9	0.1
C	0.9	1.0	0.8	0.1	0.9	0.2	0.9	0.8	0.2
D	1.0	0.1	0.9	0.9	0.8	0.3	0.7	0.1	0.9
E	0.1	0.9	0.1	0.5	0.2	0.1	0.4	0.3	0.2

Table 2. Comparsion of results

Provison support of insomnia	Results	Previous work
Informational supports	Low negative events	[26]–[28]
Emotional supports	Emotion-focused coping	[29]–[31]
Companionship supports	Mutual interest with recipient	[32]–[34]
Instrumental supports	Problem-focused coping	[35]–[37]

4.1. Simulation trace for insomnia provision preferences

– Case # 1: Informational insomnia supports (limited personal resources and low negative events):

The personality attributes for individual A are high and also high knowledge level about the problem, therefore he/she will cope with the incoming negative events through provided informational support as shown in Figure 2(a). Moreover, it is shows that individual A developed better coping skills through the selection of emotion-focused coping since he/she has insufficient resources and high negative events and in last threat faced as primary stressors. Similar findings can be found in [26]–[28].

– Case # 2: Emotional insomnia supports (limited personal resources and highly negative events):

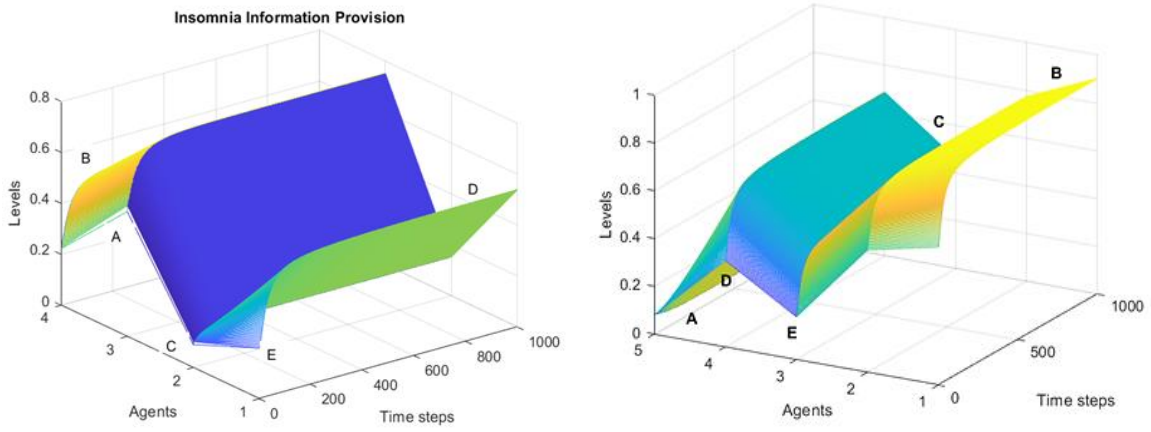
Normally, an individual with a high agreeableness personality (individual B) with perceived close tie is high, prefers to provide emotional support as a mechanism to help recipient as shown in Figure 2(b). Similar findings can be found in [29]–[31]. In addition, individual C provides also emotional support but less than individual B since he/she has lower value for perceived close tie.

– Case # 3: Companionship insomnia supports (highly personal resources and low negative events):

A person with high with extraversion personality (individual D), tends to provide companionship support as a coping process see Figure 3(a). These results are in line with existing literature as in [32]–[34]. In this simulation trace, it is observable that individual C also provide companionship support but lesser than individual D since he/she has lower mutual interest with recipient situation.

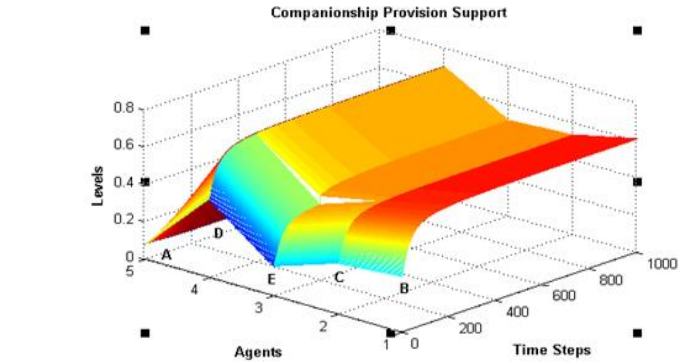
– Case # 4: Instrumental insomnia supports (highly personal resources and highly negative events)

In this simulation, individual C provide the highest value of instrumental support. One of the factors can be used to explain this simulation is the increasing level of provider's personal resources. Since he/she has the higher personal resources compared with other individuals A, B, and E as shown in Figure 3(b). For example, several studies reported that providers who were satisfied with helping others used more problem-focused coping [35], [36].

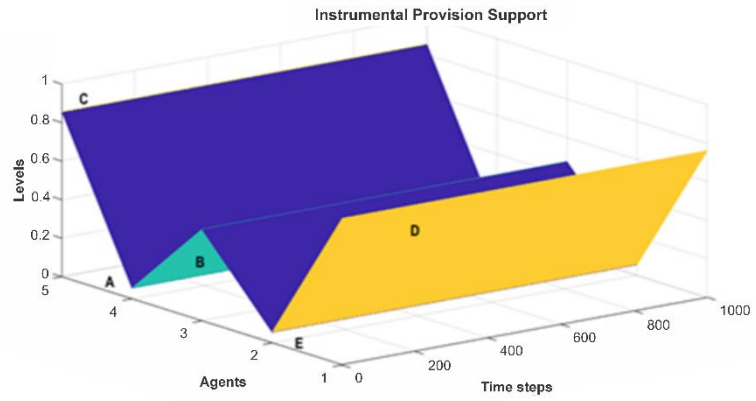


(a) (b)

Figure 2. Insomnia provided support: (a) informarional and (b) emotional preferences



(a)



(b)

Figure 3. Insomnia provided support: (a) companionship and (b) instrumental preferences

4.2. Mathematical analysis

The determination of the model's equilibria is based on the mathematical formal analysis as mentioned in [35], [36]. The equilibria describe the condition in which the values for the variables that experienced stable situations. Theoretically, this total to almost 3^3=27 possible equilibria. As the number of possible combinations is enormous, developing a complete classification of equilibria is rather difficult. However, the analysis can be pursued further for some typical cases. It must be noted that for each distinguished case more information is available regarding the equilibrium values of the other variables based on the additional non-dynamic equations.

– Case #1: $Eh = Ma \wedge Cm = Wh$

In this case, from (7), this case is equivalent to: $Bl = (1 - [\gamma_b . Pf + (1 - \gamma_b) . Sf \rightleftarrows \rightleftarrows]) . (\sigma_b . Ma + (1 - \sigma_b) . Ef \rightleftarrows)$. Assuming γ_b and σ_b equal to *0.5*, therefore; $Bl = (1 - [Pf + Sf \rightleftarrows \rightleftarrows]) . (Ma + Ef \rightleftarrows)$. From (8), this case gives; $Ma = \omega_m . Ef + (1 - \omega_m) . [(1 - [Pf + Sf \rightleftarrows \rightleftarrows]) . (Ma + Ef \rightleftarrows)]$. Rearrange; $Pf = 1 - Sf - (Ma - Ef)/(Ma + Ef)$ and $\omega_m \neq 1$. Consider (9), the equilibria point is $Ba = 1 - Sf - (Ma - Ef)/(Ma + Ef) + (1 - Bl)$.

– Case #2: $Cm = 1$

Assuming Wi_1 and Wi_2 are nonzero, thus (14) provides equilibria point of; $Ip = Kl . Wh$. Using the same principle for (15), the effect of the stability point can be summarized as; $Ep = Wh . [Ag + Pc]$.

– Case #3: $Eh = 1$

In this case, from (7), this case is equivalent to: $Bl = (1 - [\gamma_b . Pf + (1 - \gamma_b) . Sf \rightleftarrows \rightleftarrows]) . (\sigma_b + (1 - \sigma_b) . Ef \rightleftarrows)$. If γ_b and σ_b are nonzero nor one, then $Bl = (1 - [Pf + Sf \rightleftarrows \rightleftarrows]) . (Ef \rightleftarrows)$. Rearrange this, $Bl / Ef = (1 - [Pf + Sf \rightleftarrows \rightleftarrows])$.

5. CONCLUSION

The insights gained from this study have three important implications. First, this research enhances the theoretical framework surrounding insomnia and social support by integrating computational modeling with psychological literature. It provides a new perspective on how SSN function in the context of insomnia. Second, the model can be used to develop assistive technologies and interventions aimed at improving support for individuals with insomnia. For example, assistive agents or applications could be designed to provide real-time support and coping strategies based on the model's findings. Third, the findings can inform policies and training programs for healthcare providers, family members, and other caregivers, emphasizing the importance of understanding cognitive and emotional processes in providing effective support to individuals with insomnia. To build upon the findings of this study, future research should conduct empirical studies to validate the model's predictions and simulations against real-world data. While this paper presents a comprehensive computational model for understanding insomnia and social support, several limitations must be acknowledged:the model is primarily based on theoretical constructs and simulation data, which may not fully capture the complexity of real-world scenarios. Furthermore, using generated simulation traces, the model has been verified against a number of properties describing emerging patterns put forward in the literature. The resulting model can be useful to understand how certain concepts in a societal level (for example; personality attributes) may influence social providers while coping with insomnia. In addition to this, it could be used as a mechanism to develop assistive agents that are capable to support individuals when they are facing sleeplessness during a social support process. In conclusion, while the presented computational model offers valuable insights into the interplay between insomnia and social support, addressing its limitations through future research will enhance its applicability and impact, ultimately contributing to better support strategies for those affected by insomnia.

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