An Ambient Agent Model for Support of Informal Caregivers During Stress

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Abstract. Caring for a depressed person may have substantial impact on the health and well-being of the caregiver. In this paper, an ambient agent model is proposed that supports caregivers, to prevent or decrease the burden in them and promote their well-being. The agent integrates a domain model of the functioning of the caregiver and the care recipient and their interaction, and exploits model-based reasoning to assess the caregiver's state in order to generate dedicated actions that are tuned to the circumstances.

Keywords: Integrative ambient agent model, caregiver stress, caregiving interactions, intelligent support.

1 Introduction

Ambient Intelligence applications in the health area usually focus on providing support for persons suffering from some disease or mental disorder (e.g., [1]). For the mental health area applications have been designed to monitor and support persons suffering from depression (e.g., [2]). However, often also persons in the daily environment of a depressed person are affected and may experience a heavy burden as an informal caregiver. In the therapeutic area also support for such informal caregivers, such as partners or family members has been developed; see, for example [7]. This paper focuses on these informal caregivers.

An ambient agent model is presented to provide support to caregivers, based on monitoring and assessing the situation of both the caregiver and care recipient, and determining dedicated support actions. The ambient agent model uses a computational model for caregiving interactions, adopted from [3], and exploits model-based reasoning to monitor and assess the situation, and guidelines adopted from [7] in order to generate support actions (based on these assessments) that are tailored to the persons and their states.

In the paper, first in Section 2 the adopted computational (domain) model for caregiving interactions is briefly described. Next, in Section 3 the ambient agent model integrating this domain model is presented. In Section 4 a number of simulation results for different types of scenarios are discussed. Section 5 addresses formal verification of simulation results. Finally, Section 6 is a discussion.

2 A Domain Model for Caregiving Interactions During Stress

In this section, the domain model used is presented. This dynamic model for informal caregiving interactions during stress was adopted from [3]. This model will serve as a basis for later use in an analysis and a support model. Fig. 1 depicts a global description of relevant states within the model and the relations between the states. In the figure, the states that are depicted in grey represent states that have been used as a monitoring component. In addition, the states in bold lines represent the point of impacts of support provided by an intelligent support agent. Basically, there are three important aspects play vital roles to maintain social support and caregiver's wellbeing, namely; (1) incoming stressors (from the environment (negative events), and care recipient (primary stressor)), (2) mediating conditions (coping, personal attributes), and (3) caregiver outcomes (emotional exhaustion, personal gain, stress, and support provision) [6]. In the model, a number of states have been defined, whereby each state is represented by a number between 0 (low) and 1 (high). In the previous model, two interconnected models (caregiver and care recipient models) were involved, however for the purpose of this paper, only a caregiver model has been used in a detailed manner, and the recipient model has been used in a more abstracted form. To represent the relationships over time in agent terms, subscripts are used with an agent's

name *A* (caregiver agent). In addition to this, the current value for all of these temporal relations is related to the previous respective attribute. Note that the change process is measured in a time interval between t and $t+\Delta t$. The operator Pos for the positive part is defined by $Pos(x) = (x + |x|)/2$, or, alternatively; $Pos(x) = x$ if $x \geq 0$ and 0 else.

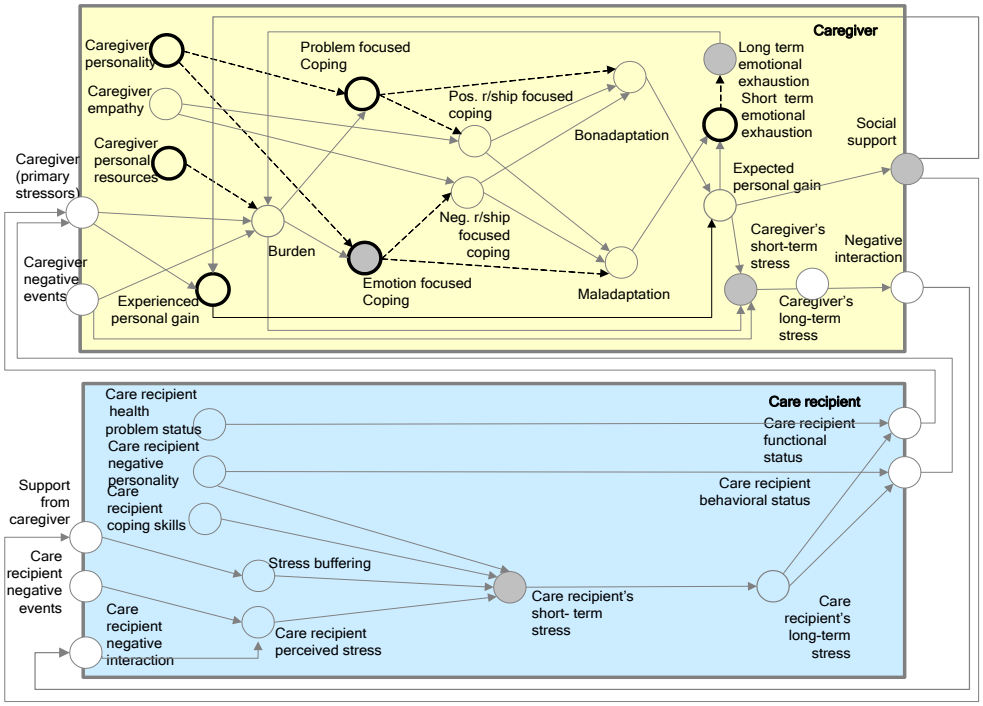

Fig. 1. Overview of the Domain Model for Caregiving Interactions During Stress

First, the state of burden will be explained. The state *burden* (*Bd*) is used to express what caregiver feels when dealing with the combinations of *primary stressor* (*GpS*), *negative events* (*NgE*), and *emotional exhaustion* (*ExH*). If the caregiver has adequate personal resources (*GpR*), it will dampen the progress of burden level; otherwise it will lead to the formation of *caregiver's short-term stress* (*GsS*), and later will build up as *caregiver's long-term stress* (*GlS*).

$$Bd_A(t)=[\beta.GpS_A(t)+(1-\beta).ExH_A(t)].(1-GpR_A(t)). \quad \textbf{(1)}$$
$$GsS_A(t) = [\phi.GnE_A(t) + (1-\phi).Bd_A(t)].(1-PgN_A(t)). \quad \textbf{(2)}$$
$$GlS_A(t+\Delta t)= GlS_A(t) + \varphi.(GsS_A(t)-GlS_A(t)).(1-GlS_A(t)).GlS_A(t)].\Delta t. \quad \textbf{(3)}$$

Coping skills (*problem-focused coping* (*PfC*), and *emotional-focused coping* (*EfC*)) are influenced by *burden* and *caregiver personality* (*GpP*). Note that if a person experiences a very high level burden will have the effect that the possibility for him to choose *problem-focused coping* becomes smaller and it is a contrary condition for *emotional focused coping*.

$$PfC_A(t) = GpP_A(t).(1-Bd_A(t)). \quad \textbf{(4)}$$
$$EfC_A(t) = (1-GpP_A(t)).Bd_A(t). \quad \textbf{(5)}$$

Positive relationship focused coping (RfC^+) depends on the relation between *problem focused coping* and *caregiver's empathy* (*GE*). A high empathy will increase this function, while reducing its counterpart (*negative relationship focused coping* (RfC^-)). Other important state is a condition where either caregiver meets the need of caregiving outcome (*bonadaptation*) or otherwise (*maladaptation*). *Bonadaption* (*Bn*) is related to the high personal accomplishment (*expected personal gain* (*PgN*)), and *provided support* (*ScP*). *Maladaptation* (*Md*)is linked to the development of *short-term exhaustion* (*EsH*), while *expected personal gain* will reduce this effect.

$$RfC_A^+ = PfC_A(t).GE_A(t). \quad \textbf{(6)}$$
$$RfC_A^- = EfC_A(t).(1-GE_A(t)). \quad \textbf{(7)}$$
$$Md_A(t) =[\Upsilon.RfC_A^-(t)+(1-\Upsilon).EfC_A(t)](1-RfC_A^+(t)). \quad \textbf{(8)}$$
$$Bn_A(t) =[\rho.RfC_A^+(t)+ (1-\rho).PfC_A(t)].(1-RfC_A^-(t)). \quad \textbf{(9)}$$
$$EsH_A(t) = Md_A(t).(1-PgN_A(t)). \quad \textbf{(10)}$$

Experienced personal gain (*EpN*) can be measured by comparing the level of provided support, and the effect of that support towards well-being of the care recipient. Finally, consistent exposure of short-term exhaustion will increase the level of *long-term emotional exhaustion*.

$$EpN_A(t+\Delta t)=EpN_A(t)+ \vartheta.[(Pos\ ((Scp_A(t)- GpS_A(t))–EpN_A(t)).(1-EpN_A(t))) - Pos(- ((Scp_A(t)-GpS_A(t)) – EpN_A(t)).EpN_A(t))].\Delta t. \quad (11)$$

$$ExH_A(t+\Delta t) = ExH_A(t)+\gamma.[(Pos(EsH_A(t)- ExH_A(t)).(1-ExH_A(t)))- Pos(-(EsH_A(t)-ExH_A(t)).ExH_A(t))].\Delta t. \quad (12)$$

Parameters ϕ, β, Υ, and ρ provide a proportional contribution factor in all respective instantaneous specifications. Furthermore, the rate of change for all temporal specifications are determined by flexibility rates, γ, ϑ, φ, and ψ, respectively.

3 The Integrative Ambient Agent Model

After the discussion of the domain model, this section focuses on the integrative ambient agent model used to support caregivers. A basic element in the ambient agent model is the integration of domain model within it. By incorporating the domain model, an ambient agent gets an understanding of the processes of its environment [1], [2]. Basically, there are two different ways to integrate a domain model within agent model [4]. First, the domain model is used as a basis to perform analysis of the human's states and processes by reasoning on observations and specific sensors (analysis model). Second, the domain model is used as a foundation to provide support for the human (support model). These two models are used within the two corresponding components within the ambient agent model. Fig. 2 (dotted arrows, left hand side) shows these two types of integration of the domain model in the ambient agent model. A third way of using the domain model is as an agent model to simulate human behaviour in order to test the ambient agent model (dotted arrow in Fig. 2, right hand side).

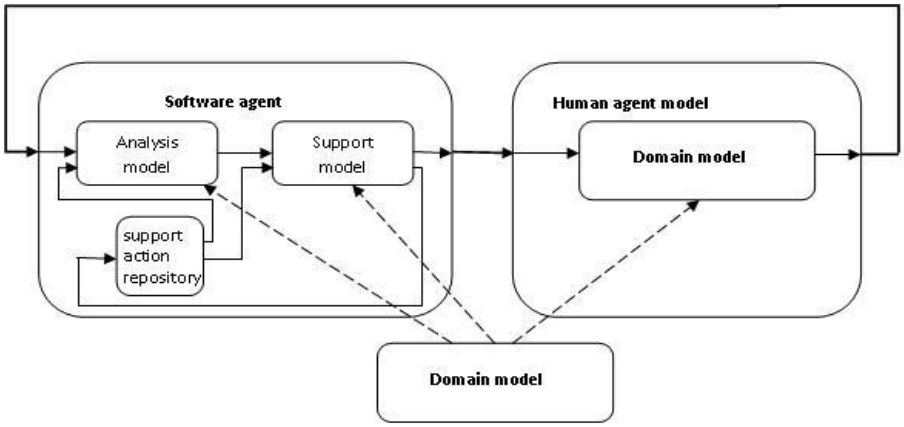

Fig.2. The integration of a domain model within an agent model

In Fig. 2, the solid arrows indicate information exchange between processes. In the ambient agent model, another component is introduced, namely a support action repository. This additional component keeps track of the generated support actions given by the ambient agent to the caregiver. Note that there two incoming arrows to the analysis component. The first arrow provides information about the environment (care recipient stress, personality and resources), the second arrow provides information about already provided support to the caregiver (from the support action repository). The outcome of the analysis component has the form of assessments, and is used as input for the support component, another incoming arrow for the support component provides the already selected support actions and their frequency from the support action repository. The outgoing arrows from the support component define provided support actions to the caregiver, and support action repository. The support action repository will update the frequency of provided support action from this information. In the next section, the details of the analysis and support component will be discussed.

3.1 The Analysis Component

First the analysis component is addresses; see Fig. 3. To be able to analyse the dynamics of the caregiver's and care-recipient's conditions, an ambient agent should be equipped with a domain model such as the one introduced in Section 2. Based on this knowledge, the ambient agent is able to have some understanding of the hu-

man processes and actions. Hence, the model for analysis in principle should include approximately the equivalent concepts as in the domain model. Note that not all concepts that exist in the domain model can be physically observed by the ambient agent [4]. For example, the level of 'experienced personal gain' is not something that is explicitly observable in the real world.

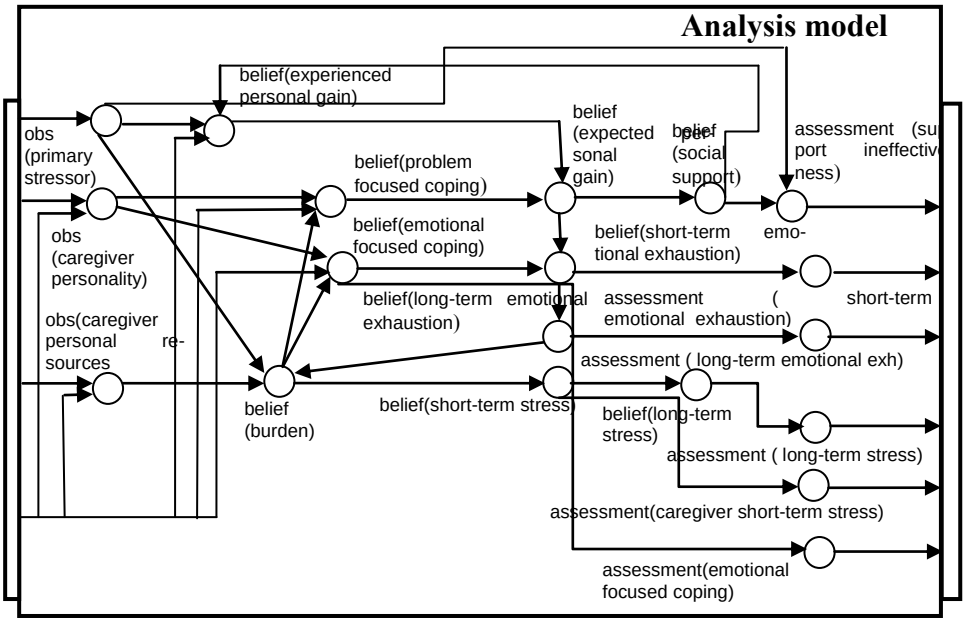

Fig.3. Overview of the Analysis Model for the Caregiving Processes

To overcome this issue, the agent approximates values for such nonobservable variables by using beliefs derived using the integrated domain model. To capture important essences in analyzing caregivers' states, the following concepts are needed: (1) observations of primary stressors, caregiver personality and personal resources, (2) beliefs in (problem and emotional focused) coping characteristics, (3) beliefs in emotional exhaustion (short and long term), (4) beliefs in burden, (5) beliefs in experienced and expected personal gain, (6) beliefs in stress (short and long term), and (7) beliefs in social support. As can be seen, these concepts are similar to the concepts explained in Section 2, but as a form of integration embedded in observations or beliefs. For example, the concept of belief about an value V at time t for the variable of the domain model named as long_term_stress is used in the analysis component as belief(long_term_stress, V, t). Using these embeddings of domain concepts, the ambient agent model is able to assess a caregiver's conditions and provide this information as inputs to the support component,using dynamical relations between such beliefs based on the corresponding dynamical relations in the domain model. For example, suppose in the domain model the following relation is given specifying how state variable y depends on state variables x_1, x_2, x_3: $y(t+\Delta t) = y(t) + f(x_1(t), x_2(t), x_3(t))\ \Delta t$. Then this is integrated in the analysis model as (where $\rightarrow$ denotes a temporal causal relation):

$$\text{belief}(x1, V1, t) \wedge \text{belief}(x1, V2, t) \wedge \text{belief}(x3, V3, t) \rightarrow \text{belief}(y, f(V1,V2,V3), t+\Delta t)$$

Fig. 3 provides an overview of such dynamical relations in the analysis model. Note that for simplicity of notation here the values of the states are not mentioned.

3.2 The Support Component

The support model (see Fig. 4) can be specified in two different manners. First, the ambient agent can select support using the following causal representation:

$$\text{assessment}(x1, V1) \wedge V1 > \text{threshold\_assessment\_1} \wedge \ldots\ldots \text{assessment}(xk, Vk) \wedge Vk > \text{threshold\_assessment\_k} \wedge \text{frequency\_provided\_support\_A} < \text{threshold\_frequency\_support\_A} \rightarrow \text{support\_action}(a1)$$

Here $x_1,...x_k$ represent the assessed conditions, $V_1,...,V_k$ represent observed or estimated values, and a_1 represents a support action. From this representation, the ambient agent will activate support that match the conditions expressed in the antecedents. Note that all threshold values can be specified by a user. The frequency of provided support can be obtained from the action repository, and aims to discontinue from providing a specific support if the caregiver shows no improvement after previously receiving the same support. It provides a mechanism to diversify support provided by an ambient agent.

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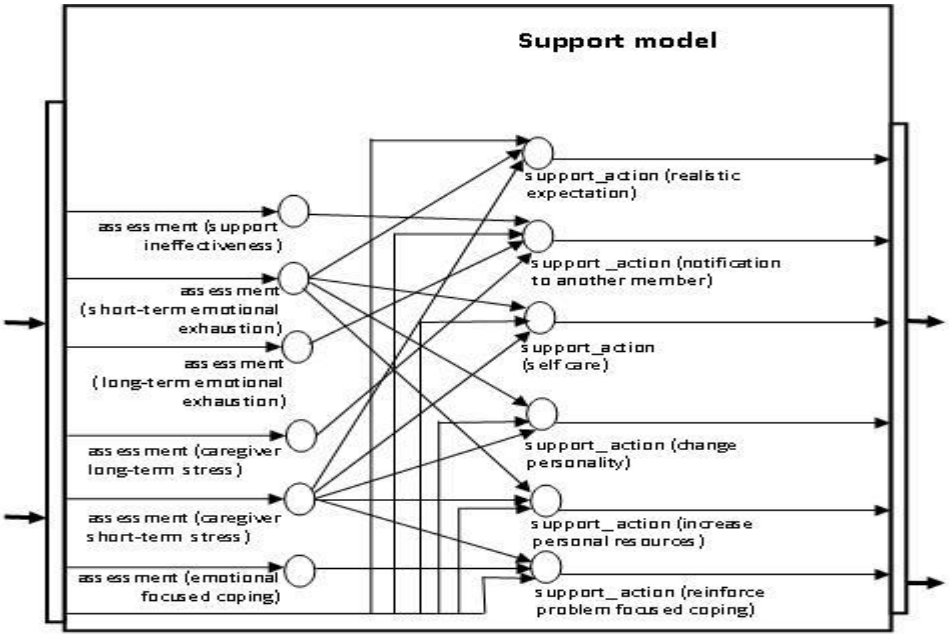

Fig.4. Overview of the Support Model for a Caregiver

Another approach to specify a support model is in a numerical manner, using the weighted networks. For this approach, each support action (e.g., a_1) will receive a summation of weighted input (y) from a set of selected assessments (x_i). For this, a form of continuous logistic function can be used, as in [14].

$$y(t) = \sum_i x_i \,.\, w_i \qquad \textbf{(13)}$$

$$f(t) = \left(\frac{1}{1+e^{-\sigma(y(t)-\tau)}} - \frac{1}{1+e^{\sigma\tau}}\right).(1+e^{-\sigma\tau}) \qquad \textbf{(14)}$$

where w is a weight vector, σ is a steepness and τ a threshold parameter. In this choice, a common practise is followed (logistic function) but other types of combination functions can be specified as well. For this approach, the connection between between the agent's assessment results and support actions is represented as follows:

$$\text{assesment}(x1,V1) \wedge .... \wedge \text{assesment}(xk, Vk) \rightarrow \text{support\_action}(a1, f(V1, ..., Vk))$$

where *f(...)* represents a combination function.

Results from the continuous logistic function will be evaluated, where a support action with the highest value will be chosen. However, to allow agent's flexibility in providing support, users can choose more support actions with second or third highest values. The details of the support component can be found in Section 4. Fig. 4 shows the relationship between results from an analysis component (assessments) and support actions.

4 Concepts and Effects in Support for Informal Caregivers

This section explains how the proposed model incorporates characteristics of effective treatments for family caregivers in general and those specific to caregivers of depressed persons. By specifying these characteristics of effective treatments for caregivers, the proposed model should be as effective as possible to current standards and knowledge.

4.1 Important Concepts in a Support Model

Zarit and Femia [15] describe four characteristics of effective treatments for caregivers: a psychological approach, multidimensionality, flexibility and sufficiency. The psychological approach refers to practicing new skills and behaviours by caregivers in a group or one-to-one interventions with a psychotherapist. Multidimensional interventions are interventions that address multiple stressors and risk factors that affect the caregiver, instead of just one stressor or risk factor. Flexibility means that an effective treatment is flexible in its set up: it should not be a scripted protocol intervention, but the intervention should be adjustable to the needs of the care-

giver [11]. Sufficiency can refer to provision of ongoing support to caregivers, for example, by ongoing support groups, follow-up sessions of an intervention. These four characteristics have been integrated in the proposed support model for family caregivers of depressed persons as follows:

The psychological approach can be found in the indirect referral to support groups by the ambient agent and in the direct support actions of 'reinforce problem focused coping', 'realistic expectations' and 'increase personal resources caregiver'. The supportive actions are set up in a way that the caregiver is instructed, how to apply general theories to his/her own specific situation and motivated to make plans how to implement these new skills. The ambient agent also gives the caregiver feedback on how he/she is implementing the new skills. The proposed model is also multidimensional, in that it focuses on many possible stressors and risk factors of the caregiver (personality, finances, coping skills, thinking skills, own health). Flexibility in the proposed model can be found in the continuous monitoring of the caregiver by the ambient agent and therefore continuous adjustment of the intervention to the needs of the caregiver. Finally, sufficiency is also integrated in the proposed model by providing ongoing support to the caregiver. Sufficiency and flexibility are the main advantages of the proposed model. The multidimensionality and psychological approach are still open for new insights from research.

Next, it is explained how characteristics of treatments, specially, for caregivers of depressed persons were integrated into the proposed model. Cuijpers [7] describes an intervention for family caregivers of depressed persons, based on his experience. There are eight ways for caregivers to deal with the depressed person they care for, which are shown (translated from Dutch) in Fig. 5.

Fig. 5. Eight steps in the intervention of family caregivers of depressed persons

1. Gather information
2. Do not try to cure the depression.
3. Keep life simple.
4. Communicate better
5. Don't give too much criticism, do not get too involved.
6. Take good care of yourself
7. Watch relapse signs after recovery.
8. Watch out for suicidal signs.

These eight steps are integrated in the proposed model, as well as the seven ways as Cuijpers describes to relieve the burden or stress experienced by the caregiver, shown in Fig. 6, (translated from Dutch) [6].

1. Dealing with your emotions/feelings,
2. Take good care of yourself,
3. Learn to think different,
4. Learn to relax,
5. Make a good time planning
6. Change your social interaction with the depressed person
7. Be assertive

Fig. 6. Seven ways to relieve the burden or stress experienced by the caregiver

The current support model consists of multiple supportive actions advised by the ambient agent to the caregiver. The first support action is called "increase personal resources caregiver". This support action is aimed at teaching the caregiver to manage stress, which will decrease the burden. Examples are teaching the caregiver to make a to-do list and becoming more assertive, like in points 5 and 7 in Fig. 5. This will affect the caregiver's personality (as in changing his/her stress reactions: now he/she gets well organised, and more assertive) and the caregiver's social and financial resources (as in getting financial/practical help from friends/family).

The second support action is called "reinforce problem focused coping caregiver". Here the ambient agent teaches the caregiver how to learn to apply problem focused coping instead of emotion focused coping and gives feedback. Research shows that coping is a learnt behaviour, see a review in: [13]. Examples are: text messages or instruction movies on phone/through emails, in which it is shown how to deal in certain situations or dialogues with the depressed person. Also the ambient agent will ask to plan and report the new skills the caregiver has to apply, so it can monitor the newly developed skills and give feedback to the caregiver. This support action decreases the caregiver's emotion focused coping and increases the caregiver's problem focused coping: increases. These skills fall under points 2-5 in Fig. 5 and 1,3,6,7 in Fig. 6.

The third and fourth support actions are called "realistic expectations and self-care caregiver". In these actions, the ambient agent gives information about the illness so the caregiver gets an understanding of the behavioural patterns and needs of the depressed person (corresponding to point 1, Fig. 5). Also the ambient agent teaches the caregiver to take care of him/herself (physically, emotionally, and mentally) and asks for reports and plans and gives feedback (points 6 Fig. 5, points 2, 4, Fig. 6). Examples are: text messages or movies on

phone/through emails, in which examples of the behaviours of other depressed persons are given, like how fast they recover or relapse. Giving tips in self-care, like taking a time-out, finding social support, eating healthy, exercising regularly and learning relaxation exercises. These support actions increase the caregiver's experienced personal gain, because (s)he experiences less disappointments as the caregiver learns to have more realistic expectations towards the depressed person [10]. The caregiver's short term emotion exhaustion will also decrease.

The fifth support action is aimed at other persons than the 'main' informal caregiver, namely other (possible) caregivers, friends of the 'main' caregiver, or a specialist like a doctor or therapist. This support action is called giving warning and refers to the ambient agent giving information to another person than the caregiver it is supporting. This information contains a warning signal that the depressed person and the caregiver both need support from others. The effect of support from an ambient agent to the caregiver will be dealt in the next section.

4.2 Dynamics Specifications of the Effects from a Support Model

Previously, several important concepts of agent's supports were introduced. Using those concepts, it is possible to specify computational properties to visualize the effects from the support provided by a support agent. The dynamic specifications of an agent-based support can be structured pertinent to the purposes of the support, namely; (1) to reduce long-term exhaustion in a caregiving process, (2) to develop problem-focused coping skills, and (3) to improve personality attributes that reduce the physiological signs of stress [6][8]13]. The asterisk sign (*) is used to represent the extended equations about the effect of support of a caregiver's processes.

Support to reduce long-term emotional exhaustion. In this case, the support agent aims to reduce further negative influences that cause emotional exhaustion. From Table 1, the support agent will provide important advices and suggestions to regulate self-care to increase external personal resources, and to foster more realistic expectations. The effect of short-term emotional exhaustion after following agent's support is estimated after adding a new support parameter, δ_{SA} and a self-care effect into the original equation (Equation (10)). This indicates that when self-care, $Sc(t) \rightarrow 1$ and $\delta_{SA} \rightarrow 1$, then the short-term emotional exhaustion is recuced to zero. Another important effect after following the support is having more external personal resources. Thus, a new caregiver personal resource (GgR^*) can be expressed as having a combination of existing resources (GpR) and external resources (Ep).

$$EsH^*_A(t) = Md_A(t).(1-PgN_A(t)).(1-\delta_{SA}.Sc(t)) \quad \textbf{(15)}$$

$$GgR^*_A(t) = \delta_{EA}.\ GpR_A(t) + (1-\delta_{EA}).Ep(t) \quad \textbf{(16)}$$

The new value of experienced personal gain depends on a combination of the previous equation in (11) and support contribution when a person is capable to achieve realistic expectations (Re).

$$EpN^*_A(t+\Delta t)=EpN_A(t)+ \mathcal{G}.(\delta_{RA}.[(Pos((Scp_A(t)-GpS_A(t))- EpN_A(t)).(1-EpN_A(t))) - Pos(-((Scp_A(t)-GpS_A(t))- EpN_A(t)).EpN_A(t))] + (1-\delta_{RA}).Re(t).(1-EpN_A(t))\Delta t. \quad \textbf{(17)}$$

Support to reduce dependency on emotional-focused coping skills: In order to visualize the effect when a person follows agent's advices to reinforce problem-focused skills, both new problem-focused and emotional-focused coping skills are calculated as follows:

$$PfC^*_A(t) = GpP_A(t).(1-((1-\delta_{FA}.Rp(t)).Bd_A(t))). \quad \textbf{(18)}$$

$$EfC^*_A(t) = (1-GpP_A(t)).Bd_A(t).(1-\delta_{FA}.Rp(t)). \quad \textbf{(19)}$$

where δ_{FA} determines the influence of the acceptance in change coping skills and Rp represents reinforce problem focused coping skills.

Support to reduce physiological signs of stress: For this type of support, changes in both caregiver personality and resources are needed. In this case, a new caregiver personality (GpP^*) is calculated by combining the existing personality, and the positive personality (Cp) from the support. Equation (14) provides similar effect for the new caregiver resources.

$$GpP^*_A(t) = \delta_{PA}.GpP_A(t) + (1-\delta_{PA}).Cp(t) \quad \textbf{(20)}$$

In addition to this, δ_{EA}, δ_{RA} and δ_{PA} are support-acceptance parameters; it represents a person's ability to accept respectives changes from the support.

5 Some of the Simulation Results

The ambient agent model presented in Section 3, integrating the domain model as described in Section 2 was implemented in Matlab in order to perform simulation experiments. For the simulations, the functioning of the designed system was explored in interaction with three fictional types of caregivers (caregiver 1 (CG1), caregiver 2 (CG2), and caregiver 3 (CG3)). Both caregivers (1 and 2) are ineffective caregivers and susceptible for long-term stress in a caregiving process (low in positive personality and resources), while caregiver 3 is an effective caregiver. In this case, caregiver 1 ignores the support provided by the intelligent support agent, and caregiver 2 follows the support. In addition to this, information about the care-recipient's (CR) stress buffer and long-term stress has been used to measure the outcome of the agent support (as in [2]). The care-recipient stress buffer represents a process of support protecting the care recipient from potentially adverse effects of stressful events (stressors). Therefore, many studies have shown that a high stress-buffer level will reduce the development of care recipient long-term stress level in future [6][9]. In this simulation, our care recipient is experiencing negative events (stressors) and expects supports from a caregiver (also facing incoming stressors).

Table 1. Initial Values for the Simulation Experiments

	Caregiver 1 (CG1)	Caregiver 2 (CG2)	Caregiver 3 (CG3)	Care recipient (CR)
CG personality	0.2	0.1	0.8	-
CG personal resources	0.2	0.1	0.7	-
CG empathy	0.3	0.3	0.7	-
CR personality	-	-	-	0.3
CR coping skills	-	-	-	0.1

These conditions are chosen to show the effect of different effects on the long-term stress, emotional exhaustion, provided support, and on the influences of the support. in addition to this, there are several parameters that can be varied to simulate different characteristics. However, in this simulation, we used the following settings: t_{max} = 1000 (to represent a monitoring activity up to 42 days), Δt = 0.3, regulatory rates = 0.5, flexibility rates = 0.2, and support-acceptance rates = 0.3. These settings were obtained from several experiments to determine the most suitable parameter values for the model. In addition, the weighted network is implemented in the support model to select the most appropriate support. To illustrate the effect of support, all caregivers receive support by the agent after half of the simulation period.

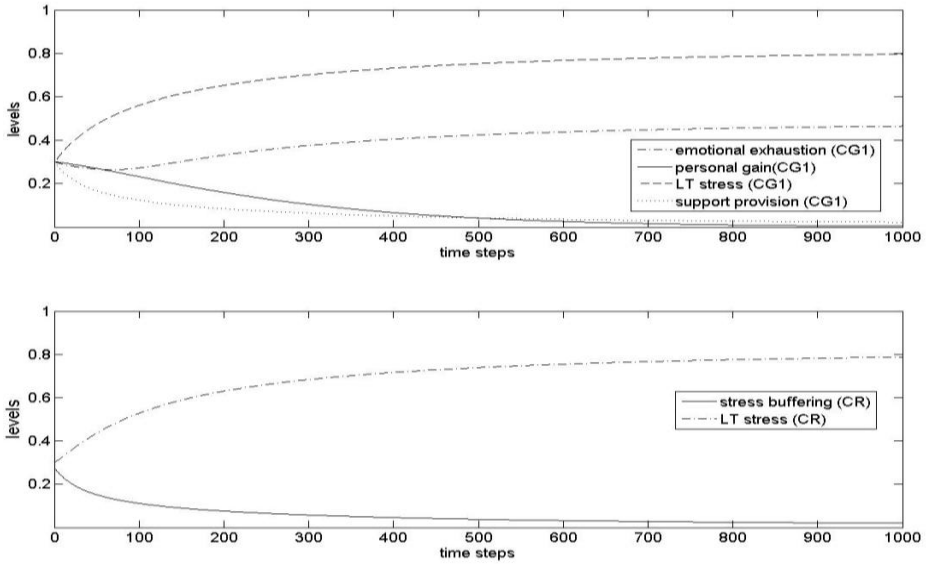

Fig.7. An ineffective caregiver (CG1) without support, and a bad care recipient (CR)

Fig. 7 visualizes a condition when the caregiver is avoiding the agent's support while facing intense stressors. Facing such events, both persons (CG1 and CR) are facing high long-term stress levels and emotional exhaustion in the long run. As a result, the caregiver is experiencing a low personal gain and support provision, which later lower the effect of stress buffering in care recipient. This condition occurs when a caregiver feel burden by the caregiving activities [12]. Eventually, without any support, both caregiver and care recipient will have a higher possibility to get depressed.

However, in Fig. 8 different scenarios can be seen when an ineffective caregiver does follow the provided support from a support agent. After following the recommended advices, the caregiver improves his / her ability to provide support. One of the precursors to explain this outcome is the increasing caregiver's personal gain. It is consistent with the findings that suggest that caregiving satisfaction encourages a caregiver to provide more support [10][12]. In addition to this, by following the specific advices, the caregiver is helped to apply more focused-coping skills, which later on influence the development of positive relationship focused coping. In many reports in the literature, problem-focused coping skills give a positive outcome in a caregiving process, for both caregiver and care recipient.

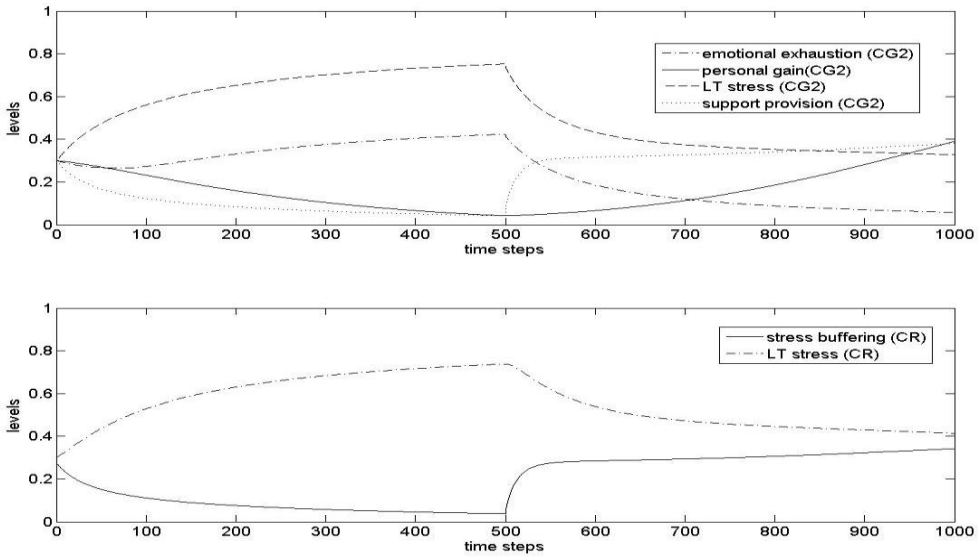

Fig.8. An ineffective caregiver (CG2) with support, and a bad care recipient (CR)

In another case (see Fig. 9), an effective caregiver requires no support from the support agent since he / she is capable to provide adequate support during the caregiving process. It is obvious to see that caregivers with more positive personality, personal resources and empathy tend to provide better support compare to those who are not [11][13]. This results in an increase of the stress buffering level, and later will dampen the development of the caregiver's long-term stress. Another interesting pattern to see is when the caregiver is experiencing repeated stressors (oscillating condition). In this case, caregiver CG1 shows monotonic increasing in his / her long-term stress. In contrary, caregiver CG2 experiences monotonic decreasing in his /her long-term stress. Similar condition also occurs in caregiver CG3 but decreases much faster and with lower oscillation compared to the condition in CG2.

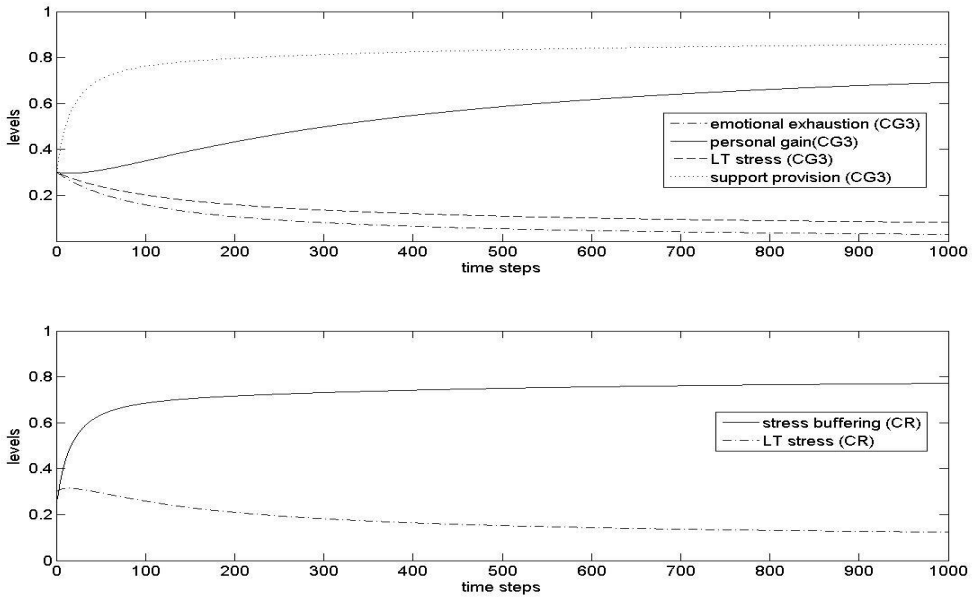

Fig.9. An effective caregiver (CG3) without support, and a bad care recipient (CR)

6 Verification of the Simulation Results

In order to verify whether the model indeed generates results that adherence to psychological literatures, a set of properties have been identified from related literatures. These properties have been specified in a language called Temporal Trace Language (TTL). TTL is built on atoms referring to states of the world, time points, and traces. This relationship can be presented as holds(state(γ, t), p) or state(γ, t) |= p, which means that state property *p* is true in the state of trace γ at time point *t* [5]. It is also comparable to the *Holds*-predicate in the Situation Calculus. Based on that concept, dynamic properties can be formulated using a hybrid sorted predicate logic approach, by using quantifiers over time and traces and first-order logical connectives such as ¬, ∧, ∨, ⇒, ∀, and ∃. A number of simulations including the ones described in Section 4 have been used as basis for the verification of the identified properties and were confirmed. Note that tb and te are the initial and final time points of the simulation period.

VP1: Monotonic decrease of long-term stress
For all time points t1 and t2 between tb and te in trace γ1
if at t1 the value of the caregiver's long-term stress is R1 and at t2 the value of the caregiver's long-term stress is R2 and t1 < t2, then R1 ≥ R2

∀γ: TRACE, ∀R1, R2: REAL, t1,t2:TIME
[state(γ,t1) |= long_term_stress(cg, R1) &
state(γ,t2) |= long_term_stress(cg, R2) &
tb ≤ t1 ≤ te & tb ≤ t2 ≤ te & t1 < t2 ⇒ R1 ≥ R2]

By checking property VP1, one can verify whether a caregiver's long term stress decreases monotonically over a certain time interval. For example, the caregiver's long-term stress turned out to decrease over the second half of the trace for caregivers that have received and accepted the provided support or for an effective caregiver.

VP2: Decrement of a caregiver's long-term stress below a certain level x
A time point t exists such that for all t1>t the value of long-term stress is at most level x.

∀γ1: TRACE, ∃t ∀R: REAL [tb < t < te &
∀t1:TIME>t [t ≤ t1 ≤ te & state(γ,t1) |= long_term_stress (cg, R1) ⇒ R1 ≤ x]

Property VP2 can be used to verify whether a variable eventually approaches some (given) value. In the experiments reported here, x = 0.3 was used as a borderline value for long-term stress to assume a caregiver is effective to provide social support. In many cases, after following the advices, the caregiver will reach this borderline value. A number of more specific other properties have been identified and verified, such as the following ones, which compare cases with a specific type of support and cases without. Note that formalisation of such comparison properties makes use of the possibility to explicitly refer to traces in the language TTL; this is not possible in the usual temporal logical languages.

VP3: Effect of problem coping skills on a caregiver's long-term stress
After a caregiver has followed the programme to improve problem focused coping skills for some time, the long-term stress level is more reduced than for a caregiver who does not.

∀γ1,γ2: TRACE, ∀R1, R2: REAL, t1,t2:TIME
[state(γ1, t1) |= support_problem_coping & state(γ2, t1) |= not support_problem_coping &
state(γ1, t2) |= long_term_stress(cg, R1) & state(γ2, t2) |= long_term_stress(cg, R2) &
t1 < t2 ⇒ R1 < R2]

VP4: Effect of realistic expectation on emotional exhaustion
After a caregiver has followed the support programme to reduce unrealistic expectation, the long-term emotional exhaustion is more reduced than for a caregiver who does not.

∀γ1,γ2: TRACE, ∀R1, R2: REAL, t1,t2:TIME
[state(γ1, t1) |= support_realistic_expectation &
state(γ2, t1) |= not support_realistic_expectation &
state(γ1, t2) |= long_term_emotional_exhaustion(cg, R1) &
state(γ2, t2) |= long_term_emotional_exhaustion (cg, R2) &
t1 < t2 ⇒ R1 < R2]

VP5: Effectiveness of support on provided support to the care recipient
A caregiver who follows the suggested support by an agent will provide better support to the care recipient than a caregiver who does not.

∀γ1,γ2: TRACE, ∀R1, R2, d: REAL, t1,t2:TIME
[[[state(γ1, t1) |= support_realistic_expectation & state(γ1, t1) |= support_problem_coping &
state(γ1, t1) |= support_add_personal_resources] &
state(γ2, t1) |= not support_realistic_expectation | state(γ2, t1) |= not support_problem_coping |
state(γ2, t1) |= not support_add_personal_resources] &
state(γ1, t2) |= long_term_stress(cg, R1) &
state(γ2, t2) |= long_term_stress(cg, R2) &
t1 < t2 ⇒ R1 < R2]

7 Discussion

In this paper, an ambient agent model was proposed that supports caregivers for depressed persons and promote their well-being. Caring for a depressed person may entail a serious risk for the health of the caregiver. The designed ambient agent integrates a domain model of the functioning of the caregiver and the care recipient and their interaction, adopted from [3]. It exploits model-based reasoning to monitor and assess the caregiver's state using this computational model. Based on these assessments dedicated support actions are generated that are tuned to the circumstances, thereby taking into account guidelines adopted from [7].

Although some applications have been designed to support persons with a depression (e.g., [2]), automated support for caregivers has not been addressed, as far as the authors know. The model introduced here was evaluated by conducting a number of simulation experiments for different scenarios and types of caregivers, and formal verification of the outcomes of these experiments. These outcomes show that using the advices provided by the ambient agent results in improvement in the situation in comparison to not using such advices; for verification of this type of comparison properties (which are not representable in the often used temporal languages; see also [5]) the language TTL and its software environment [5] has proved its usefulness.

8 References

1. Aarts, E., Harwig, R., and Schuurman, M.: Ambient Intelligence. In: P. Denning (ed.), The Invisible Future, pp. 235-250. McGraw Hill, New York (2001)
2. Aziz, A. A., Klein, M.C.A., Treur, J.: An Integrative Ambient Agent Model for Unipolar Depression Relapse Prevention. Journal of Ambient Intelligence and Smart Environments 2, 5-20 (2010)
3. Aziz, A.A., Treur, J., Wal, C.N. van der: Modeling Caregiving Interactions during Stress. In: Yao, Y, Sun, R., Poggio,T., Liu, J., Zhong, N., & Huang, J. Proceedings of the 2nd International Conference on Brain Informatics, BI'10, Lecture Notes in Artificial Intelligence, vol. 6334, pp. 263-273. Springer Verlag (2010)
4. Bosse, T., Hoogendoorn, M., Klein, M.C.A., Treur, J.: An Ambient Agent Model for Monitoring and Analysing Dynamics of Complex Human Behaviour. Journal of Ambient Intelligence and Smart Environments, to appear (2011)
5. Bosse, T., Jonker, C.M., Meij, L. van der, Sharpanskykh, A., Treur, J.: Specification and Verification of Dynamics in Agent Models. International Journal of Cooperative Information Systems 18, 167-1193 (2009)
6. Cohen, S, and Wills, T.A.: Stress, social support, and the buffering hypothesis. Psychological Bulletin 98, 310-357 (1985)
7. Cuijpers, P.: Depression: Guide for Family Members (in Dutch). HB uitgevers: Baarn (2004)
8. Folkman, S.: Personal Control, Stress and Coping Processes: A theoretical analysis. Journal of Personality and Social Psychology 46, 839–852 (1984)
9. Groves, L.: Communicating Social Support. Social Work in Health Care 47, 338-340 (2008)
10. Kramer, B.J.: Expanding the Conceptualization of Caregiver Coping: The Importance of Relationship Focused Coping Strategies, Journal of Family Relations 42, 383-391 (1993)
11. Musil, M.C., Morris, D.L., Warner, C., Saeid, H.: Issues in Caregivers' Stress and Provider's Support. Research on Aging 25, 505-526 (2003)
12. Ostwald, S.K.: Caregiver Exhaustion: Caring for the Hidden Patients. Adv. Practical Nursing 3, 29-35 (1997)
13. Shankland, R., França, L.R., Genolini, C.M., Guelfi, J.D., and Ionescu, S.: Preliminary study on the role of alternative educational pathways in promoting the use of problem-focused coping strategies. European Journal of Psychology of Education 24, 499-512 (2009)
14. Treur, J., and Umair, M.: A Cognitive Agent Model Using Inverse Mirroring for False Attribution of Own Actions to Other Agents. In: K.G. Mehrotra et al. (eds.): Proceedings of the 24th International Conference on Industrial, Engineering and Other Applications of Applied Intelligent Systems, IEA/AIE'11, Part II. Lecture Notes in Artificial Intelligence, vol. 6704, pp. 109-119. Springer Verlag (2011)
15. Zarit, S., Femia, E.: Behavioral and Psychosocial Interventions for Family Caregivers: Characteristics of effective approaches and flaws in study design. American Journal of Nursing 108, 47-53 (2008)