CMPT 394/858; Part 3 of Term Project [Model Implementation (Initial)]

Project Title: Dementia and Caregivers: Modeling the Impacts of Stress of Family Caregivers on the Quality of Care and Disease Progression to Inform Policy & Practice Interventions

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1.0 Introduction:

Drawing insights from the feedback on the previous work (Model Conceptualization, part 3,) and learning from literature (including an unpublished work), we have updated several aspects of the project. We have updated the endogenous, exogenous and ignored variables. We have also updated and expanded the model equations as a way of throwing more light on the rules that governs the actions of the variables and parameters used in the Agent-Based Modeling in particular and also providing more insights on the Discrete Event Simulation. The assumptions for the equations and thus, the data used are based on literature(1,2). Our team would still be focusing on Alzheimer's disease since it constitutes about 60-70% of Dementia cases globally (3). As of January 1, 2025, approximately 771,939 Canadians were living with Alzheimer's disease or another types of dementia, and this is predicted to be 1 million by 2030 (4). In 2022, Alzheimer's disease alone was identified as the 9th leading cause of all deaths in Canada (5). Additionally, we consider mild, moderate and severe as the levels of progression of Alzheimer's Disease. The Anylogic and equations files can be found in the team's GitHub Platform.

1.1 Endogenous, Exogenous, and Ignored Variables:

- **Endogenous Variables**:
  i. Caregiver Stress Level
  ii. Caregiver Workload
  iii. Caregiver Sleep Quality
  iv. Financial Strain of Caregiver
  v. Quality of Care
  vi. Progress of Alzheimer's Disease
- **Exogenous Variable**:
  i. Initial State of Alzheimer (Mild)
  ii. Number of adults day homes
  iii. Number of family caregivers per Alzheimer patient
  iv. Use of Professional or Formal care
  v. Mental Health Therapy/ Need for Emotional Support
- **Ignored**:
  i. impact of Alzheimer progress on other healthcare services besides Primary Care,
  ii. Long-Term Home Care
  iii. All other forms of Dementia

1.2 Mental Models of what the team intends to model

- Initial Model Concept (Please note: this is just a mental model and not a CLP. We have implemented this concept using Causal Loop Diagrams -Please see CLDs in section 2. 1)

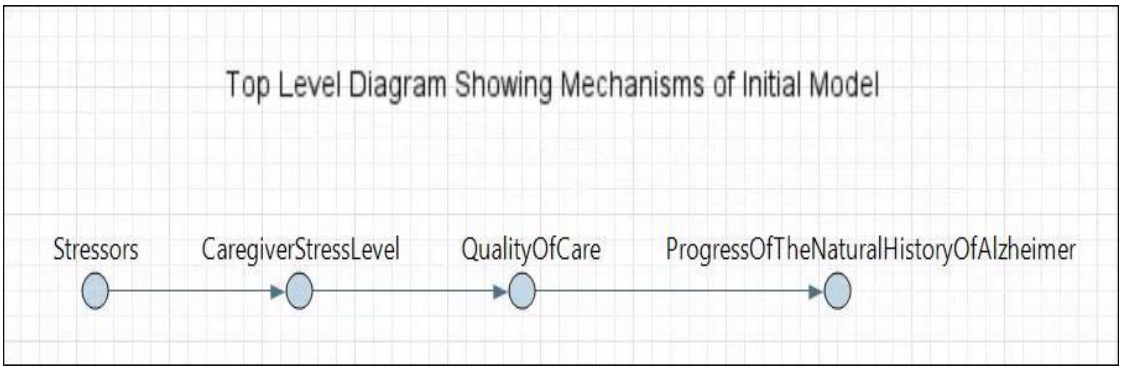


Figure 1: Mental Model for the Causal Loop Diagram Implemented in section 2.1

- Concept of Anticipated Model using a hybrid of Agent-Based Modeling and Discrete Event Simulation as implemented in section 2.2)

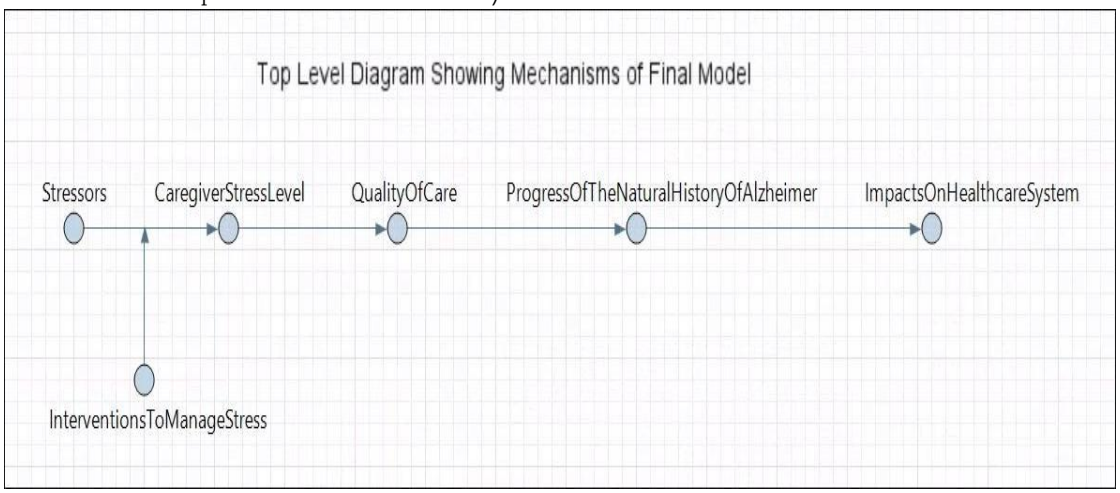


Figure 2: Mental Model of the Hybrid Model of ABM & DES Implemented in section 2.2

2.1 Causal Loop Diagram

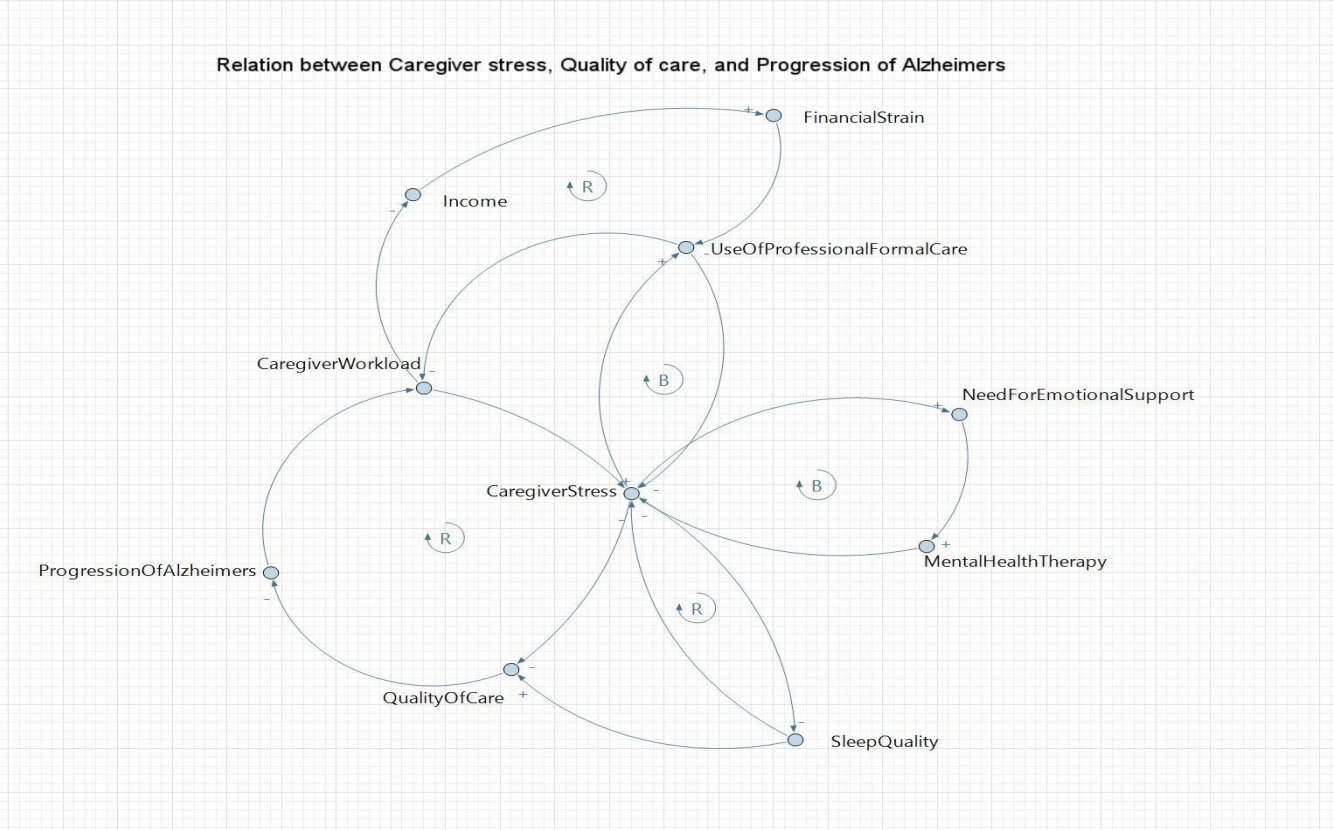


Figure 3: Causal Loop Diagram showing the relationship between some Stressors, Caregiver Stress level, Quality of Care and Alzheimer Progression.

In this updated version of the causal loop diagram, we refined and expanded the system dynamics surrounding caregiver stress, quality of care, and the progression of Alzheimer's disease. Compared to the earlier version, the final model incorporates additional feedback loops and variables that better capture both the psychological and practical dimensions of caregiving. Key improvements include the addition of Mental Health Therapy and Need for Emotional Support, which together form a balancing loop (B) that reflects how stress triggers emotional needs, leading to therapeutic interventions that help reduce caregiver stress. This complements another new balancing loop involving the Use of Professional Formal Care, which is activated under high stress and serves to reduce *CaregiverWorkload*, thereby stabilizing stress levels.

The diagram also now explicitly connects *SleepQuality* to caregiver stress, capturing a biologically grounded feedback loop: high stress reduces sleep quality, which in turn elevates stress further — forming a reinforcing loop (R). The financial strain loop has also been strengthened by showing how Income limits access to formal care, increasing workload and stress when affordability is low. Overall, the diagram now integrates both behavioral health and structural/systemic factors, offering a more holistic view of the caregiving experience. These additions allow the model to simulate a broader range of realistic interventions and outcomes, particularly useful for policy testing and agent-based modeling scenarios.

2.2: Implementation of the Hybrid Model

I. Environment for the Hybrid Model

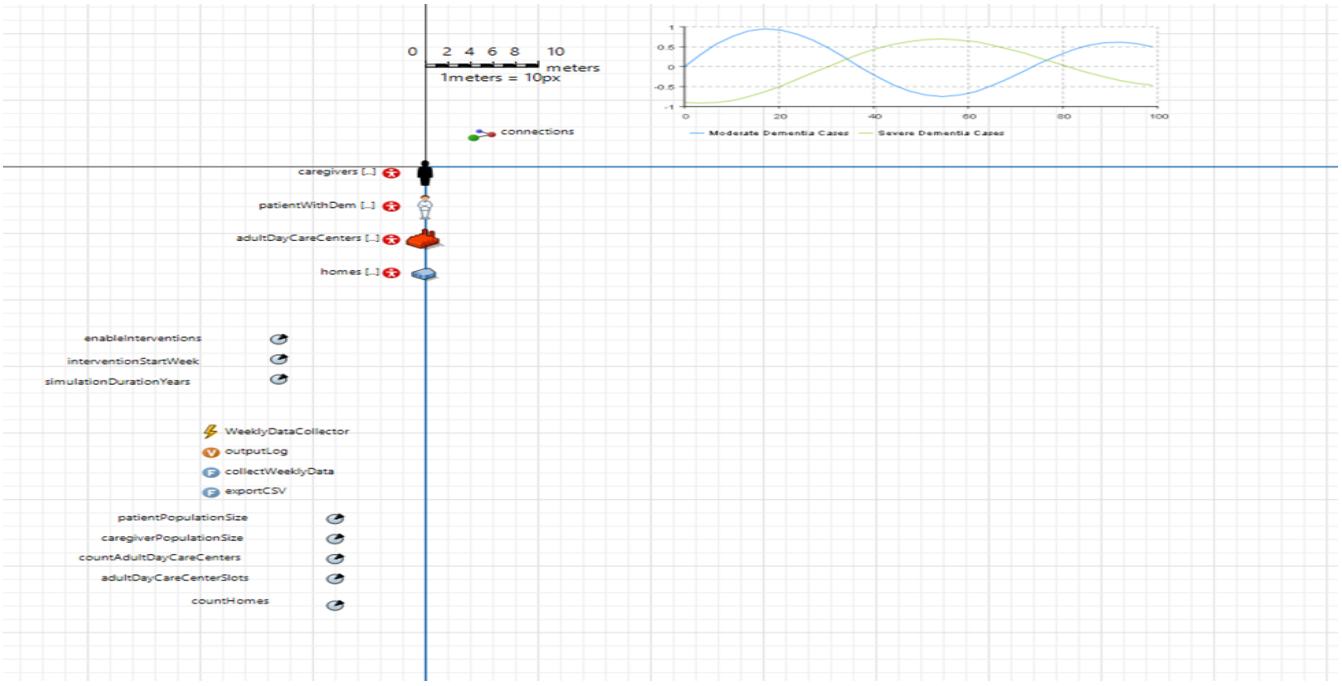


Figure 4: Main Environment of the Hybrid Model

In the current model, the Main agent sets up the simulation environment, including agent populations, parameters, and data collection. Main handles initialization of caregivers and patients with dementia, as well as intervention settings and experiment duration. Each week, Main coordinates data export and provides live tracking of overall dementia stage prevalence, supporting analysis and reporting.

II. Agent-Based Model for the Stressors – Caregiver Stress Relation

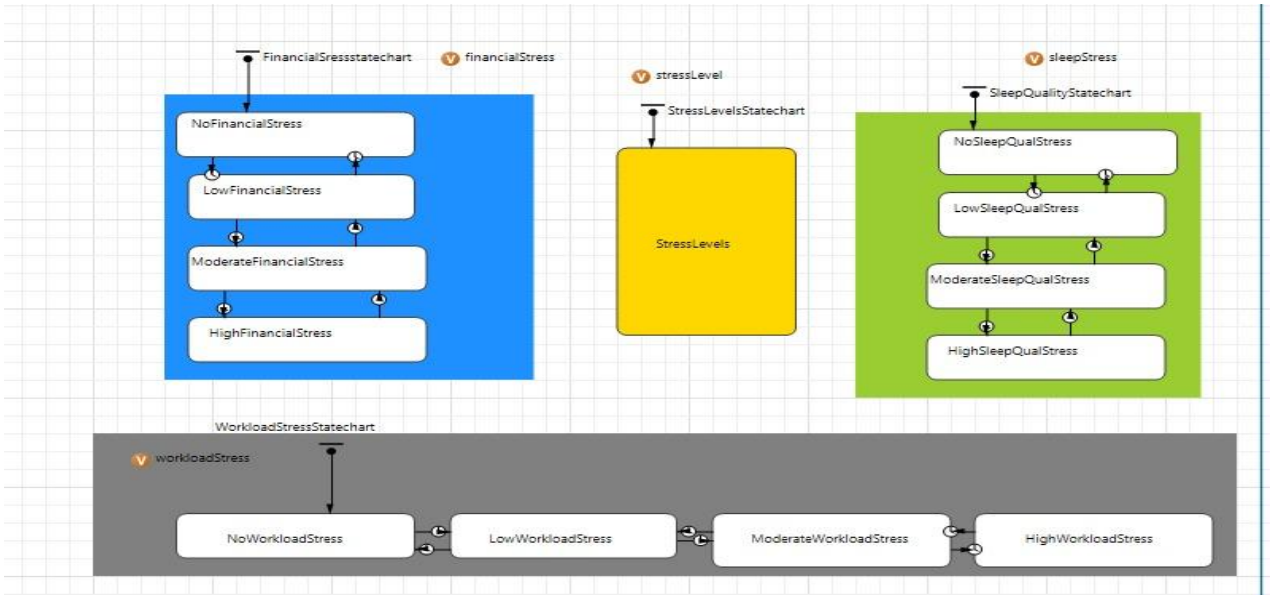


Figure 5 Agent-Based Model showing how Workload, Financial Strain & Sleep Quality impact on Caregiver Stress Level

- The Caregiver agent captures three key stressors, financial, sleep quality, and workload, using separate state charts for each. Every week, as variables like income, sleep hours, or care workload change, the stressor state charts transition between high, moderate, low, and no stress. These transitions set numerical stress values, which are averaged to a composite stress level. The central caregiver distress state chart uses this value to reflect total stress level, moving between states of low, moderate, high, crisis, and service-seeking. This system realistically captures how different stress sources combine and may trigger the search for outside help and sets up a dynamic feedback loop with the patient agent.

- In addition to these core behavioral agents, the simulation includes early-stage (barebones) definitions for additional "resource/location" agents: AdultDayCareCenter, Home, and HealthcareProvider. These classes are scaffolded but currently lack substantial internal logic, statecharts, or attributes. For now, they serve as placeholders for physical locations and healthcare processes. As the project advances, these agents will be developed further: AdultDayCareCenter will be expanded to handle resource pools and patient flow (including more detailed process modeling with blocks for allocating and releasing care slots), and HealthcareProvider will coordinate simulation of service constraints and hybrid DES dynamics.

III. Agent-Based Model showing impact of Caregiver stress level on Quality of Care

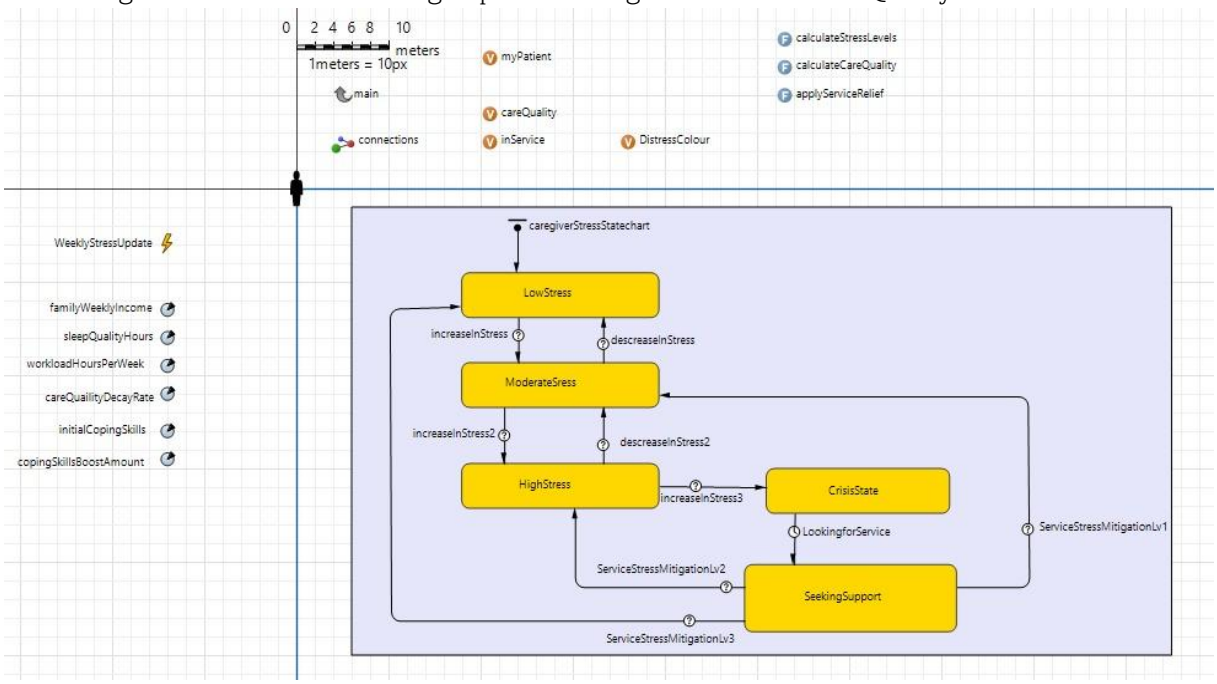


Figure 6: State Chart showing impact of Caregiver Stress Level on Quality of Care delivered to the Alzheimer Patient

The level of stress as contributed by the three stressors together triggers the quality of care to either increase, decrease or remain same, which also invariable fire Alzheimer progression. The stress level may also be adjusted from one level to the other at a time.

IV. Agent-Based Model showing the impact of Quality of Care on Alzheimer (Dementia) Progress

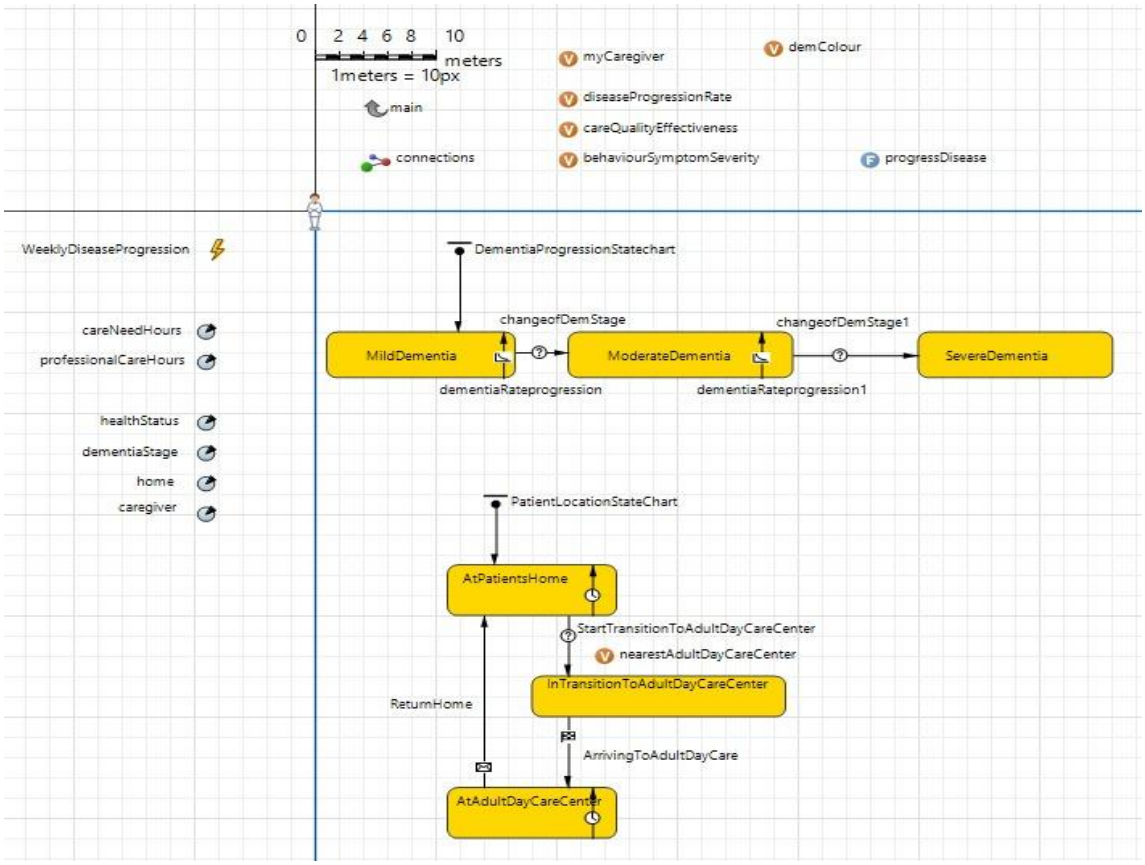
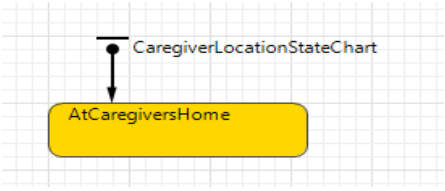


Figure 7: State Chart showing how Quality of Care by Caregiver Impact Dementia Progress

The PatientWithDem agent models a person with Dementia (Alzheimer), including variables for health status, stage progression, care needs, and behavioral symptoms. The main state chart follows disease trajectory from Mild, through Moderate to Severe Dementia, with transitions triggered by weekly health decline. Additional logic manages patient location (home versus adult day care) to simulate service interventions. The patient's variables update in line with the disease model, and the agent can affect its linked caregiver's workload and stress over time.

For the Patient Location State Chart,



V. Implementation of Discrete Event Simulation of how a Family Caregiver seeks an Adult Day Home for an Alzheimer Patient:

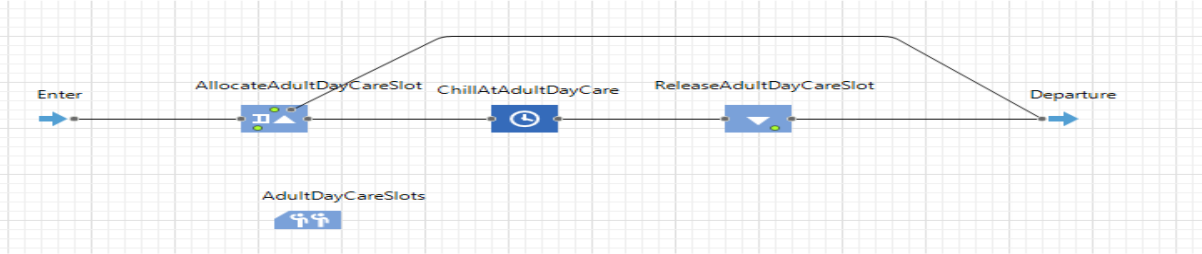


Figure 8: DES showing Need for Adults Day Home

When a patient with dementia's caregiver's stress level reaches the "SeekingSupport" state, they get moved to the InTransitionToAdultDayCareCenter state where it moves the dementia patient to the nearest adult day care centre and places them into the AdultDayCareCentre Entry Queue. Once their time is up at the adult day care centre they will be moved back to their home and the caregivers stress level will be reduced (currently gets set to 1).

3.0 Rules for Model Operation

- The following assumptions describe the **mechanisms** we intend to implement (8,9):

  i. Caregiver Stress Level (CSL) is directly proportional to the number of stressors [n(SS)] operational on the caregiver at a time: i.e., n(SS) $\propto$ CLS
  ii. Caregiver Stress Level is inversely proportional to the Quality of Care (*QoC*): $CSL \propto 1/QoC$
  iii. Quality of Care is inversely proportional to the Alzheimer progress to Severity: *Alzheimer Progress to severity* $\propto 1/QoC$

- Model Equations have been extensively described in the GitHub Portal of this Project:

- Key working equations:

1. $\sigma_C = \frac{S_W + S_F + S_S}{3}$

Where σ_C $denotes\ Caregiver\ stress\ level,$ S_w is Workload component of the Caregiver Stress Level, S_F is Financial Strain component of the Caregiver Stress Level and S_S is the component of the Caregiver Stress Level that describes the Quality of Sleep of the Caregiver. Hence;

2. $$S_W = \begin{cases} 0.0 & \text{if } H_p < 10 \\ 0.5 & \text{if } 10 \leq H_p < 25 \\ 1.5 & \text{if } 25 \leq H_p < 30 \\ 3.0 & \text{if } H_p \geq 30 \end{cases}$$

3. $S_F = \begin{cases} 3.0 & \text{if } I_w < 800 \\ 1.5 & \text{if } 800 \leq I_w < 1300 \\ 0.5 & \text{if } 1300 \leq I_w < 1900 \\ 0.0 & \text{if } I_w \geq 1900 \end{cases}$

4. $S_S = \begin{cases} 3.0 & \text{if } S_h < 28 \\ 1.5 & \text{if } 28 \leq S_h < 42 \\ 0.5 & \text{if } 42 \leq S_h < 49 \\ 0.0 & \text{if } S_h \geq 49 \end{cases}$

5. $Q_C = \max\left[0.2, min\left(1.0, ; 0.8 - \frac{\sigma_C}{3} \times 0.5 + C_S \times 0.2\right)\right]$; Q_C = Quality of Care rendered by the Caregiver.

4.0 Scenarios

The following are **"what-if" scenarios** we may want to test using the model:

- What if the concept of Adults Day-Home is introduced during the weekdays
  - i. to offer caregiver some relief
  - ii. to allow caregiver to have some time to pursue dream education/training or to work
- How does introducing a caregiver stipend affect stress levels?

5.0 Sensitivity Analyses

The following are variables we may want to **tweak/test**:

- We would want to adjust the various levels of each of the three stressors and see their impacts on the stress levels and subsequently on the quality of care and Alzheimer progress.

- Also, because "**Quality of Care**" as a variable is inversely proportional to Caregiver Stress Level, it may also be very sensitive to test the impact of different degrees of stress levels on quality of care by caregivers

6.0 Future Work:

1. We intend to adjust the linear equations (considering regression) to see the model output

2. At this stage, our focus is on completing and debugging the Java code that controls all agent logic, state chart transitions, and variable updates. Work will center on refining the transition conditions in all stressor state charts to ensure they respond correctly to weekly data and side effects, so agent states consistently match modeled equations. This will build the foundation for robust simulation runs and future intervention modules.

References

1. Government of Saskatchewan [Internet]. [cited 2025 Nov 4]. Saskatchewan's Dashboard - Average Weekly Earnings. Available from: https://dashboard.saskatchewan.ca/business-economy/employment-labour-market/average-weekly-earnings

2. Unpaid caregiver challenges and supports | CIHI [Internet]. [cited 2025 Nov 4]. Available from: https://www.cihi.ca/en/dementia-in-canada/unpaid-caregiver-challenges-and-supports

3. Dementia [Internet]. [cited 2025 Oct 15]. Available from: https://www.who.int/news-room/fact-sheets/detail/dementia

4. Alzheimer Society of Canada [Internet]. [cited 2025 Oct 17]. Dementia numbers in Canada. Available from: https://alzheimer.ca/en/about-dementia/what-dementia/dementia-numbers-canada

5. Government of Canada SC. Alzheimer's Awareness Month [Internet]. 2024 [cited 2025 Oct 17]. Available from: https://www.statcan.gc.ca/o1/en/plus/5374-alzheimers-awareness-month

6. Alorf A, Khan MUG. Multi-label classification of Alzheimer's disease stages from resting-state fMRI-based correlation connectivity data and deep learning. Computers in Biology and Medicine [Internet]. 2022 Dec 1 [cited 2025 Oct 15];151:106240. Available from: https://www.sciencedirect.com/science/article/pii/S0010482522009489

7. Alzheimer's Association [Internet]. [cited 2025 Oct 15]. Alzheimer's Stages - Early, Middle, Late Dementia Symptoms | alz.org. Available from: https://www.alz.org/alzheimers-dementia/stages

8. Cui P, Yang M, Hu H, Cheng C, Chen X, Shi J, et al. The impact of caregiver burden on quality of life in family caregivers of patients with advanced cancer: a moderated mediation analysis of the role of psychological distress and family resilience. BMC Public Health [Internet]. 2024 Mar 15 [cited 2025 Oct 17];24(1):817. Available from: https://doi.org/10.1186/s12889-024-18321-3

9. Cosio 7 Min ReadDavid, PhD, ABPP, Psychologist, Demyan IPP, PhD, et al. MedCentral. 2025 [cited 2025 Oct 17]. Caregiver Stress Syndrome Can Hinder Quality of Care. Available from: https://www.medcentral.com/geriatrics/caregiver-stress-syndrome-can-hinder-quality-of-care

10. Pei Y. Modeling distress of primary informal caregivers and evaluating supportive interventions for dementia care [unpublished work]. Saskatoon (SK): University of Saskatchewan, Department of Computer Science; 2025 Jan 8.