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A Second-Order Adaptive Decision Model for Proceeding or Terminating a Pregnancy

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Abstract This study introduces a second-level adaptive temporal-causal decision model for deciding whether to keep or not to keep a baby. In this model, different actors and factors that influence the decision-making process have been incorporated based on literature. Hereby, the actors are responsible for the Hebbian learning component and make the model adaptive. Complementary speed factors regulate when learning happens. Three scenarios for the different possible outcomes; keeping the baby, having an abortion and putting the baby up for adoption provide insights into the influences of the actors on making a decision.

1 Introduction

Every second, approximately 4.3 babies are born into this world (Malek, 2021). Subsequently, yearly in the Netherlands about 200.000 women become pregnant. When a woman becomes pregnant, she has roughly three options; keeping the baby, having an abortion and putting the baby up for adoption (FIOM, 2021). Most of the time, women decide to proceed with their pregnancy and keep their baby. For example, in 2019, 170.000 babies were born in the Netherlands. This indicates that proceeding with pregnancy is indeed the option that is chosen most often (CBS, 2021). However, as discussed, there are other options for women whose pregnancy is less planned or wanted. To indicate, in 2019 32.233 women had an abortion and 20 women put their baby up for adoption (Inspectie Gezondheidszorg en Jeugd, 2021; Werdmuller et al., 2020).

Making a potentially life-changing decision can be difficult and overwhelming (Somers, 2014). Therefore, the FIOM (Dutch specialist in the field of unwanted pregnancy) helps to guide women in their decision-making process. For instance, the FIOM recommends for a woman to gain as much (factual) information regarding her options to help her make a decision. Hereby, the FIOM states that this information can be gathered through four different actors: (i) social network (family and friends), (ii) partner (if applicable), (iii) experts (social workers, general practitioners (GPs)) and (iv) clergyman (pastor, priest, imam etc.) (FIOM, n.d.-a, n.d.-b). However, they each have different perspectives, morals, values and experiences, and can therefore influence

the women's decision in their own unique way (FIOM, n.d.-b; Somers, 2014). Besides actors, there are internal and external factors that can further affect the outcome of the decision-making process (see Section 2).

For understanding the decision-making process, an adaptive decision model is presented in this study. Hereby, decisions can be made because of learning processes over time (Treur, 2020). These learning processes are triggered by a stimulus; input from different actors. Therefore, they are called adaptive due to the adaptation of the influences on the final decision. The modelling approach of this study is based on causal relations. In addition, an adaptive learning principle called (meta)plasticity is used (see Section 2) (Treur, 2020). Hence, the objective is to understand the influences of various information sources on the decision-making process regarding keeping or not keeping a baby by modelling an adaptive decision model.

2 Background

The adaptive temporal-causal network model regarding proceeding with a pregnancy, having an abortion or putting the baby up for adoption is based on empirical data from various sources. This adaptive decision model is a model in which learning happens during decision making. First, the different actors and factors influencing the decision-making process are elaborated on. Additionally, their influence on other factors and actors are presented. Secondly, the generic learning processes are touched upon.

Partner The male partner of the woman plays a significant role in the decision-making process. For instance, he helps to contribute to the total income of the household. This income is furthermore influenced by the education of the woman. This is important as usually, the higher the level of education, the higher the total income (OECD, 2019). In this context, it is assumed that having a large and stable income typically indicates that there are resources available for supporting a baby. As a result, the pregnancy is more likely to be planned or wanted (Finer et al., 2005; Najman et al., 1990). Moreover, having a stable relationship accounted for one of the main reasons for women to proceed with their pregnancy and keep the baby. Vice versa, being single and becoming a single mother is one of the reasons women opt for the decision to have an abortion or adoption (Medoff, 1993; Minkus & Drobnič, 2021; Najman et al., 1990). Besides monetary influences, a partner also has his own opinion towards the pregnancy. In the Netherlands, the intra-household gender equality is particularly low compared to other high income European countries such as Denmark or Finland (Malghan & Swaminathan, 2021). Therefore, gender inequality portrayed in the opinion of the partner can increase the stigma around topics such as abortion, thereby affecting the decision making process (Gemzell-Danielsson & Cleve, 2017). To note, stigma is also influenced by social network and religion (see below).

Social network A supportive social network consisting of close family and friends is beneficial for decision making. Specifically, a social network can help lower the stigma regarding terminating a pregnancy, because a woman receives support and is able to discuss matters with her social network (Najman et al., 1990).

Experts Speaking with experts is not only recommended by the FIOM, but also by hospitals (Somers, 2014). Hereby, experts may include GPs, social workers, doctors and abortion clinics or adoption centres (FIOM, n.d.-a). All of these actors are qualified

to give factual and personalised information to the woman regarding her options (keeping or not keeping the baby). As a result, a woman's lack of knowledge lowers as she gains more information.

Simultaneously, a lack of knowledge is increased by stigma. To exemplify, if a woman experiences that there is stigma about abortions, she is less likely to explore her options as it is made clear not to be accepted by her community. The lack of knowledge maintained by the stigma thus increases the fear of a woman towards keeping the child (Minkus & Drobnič, 2021). This fear comprises amongst other things stress, sadness, doubt and anger towards the decision (Najman et al., 1990; Somers, 2014). As a result, fear can affect feelings towards keeping the baby and feelings towards not keeping the baby. Hereby, if the woman has little fear, she will have stronger feelings towards keeping the child. Subsequently, with the stimulus of her partner she will decide to keep the baby. Vice versa, if the woman experiences great fear, she will less likely feel like keeping the baby. Hence, the woman then remains with two options; abortion or adoption. In this case, a woman is more likely to have an abortion over an adoption if she is still obtaining education (Minkus & Drobnič, 2021). However, these options are both also influenced by religion.

Religion As mentioned before, religion influences stigma due to their morals and values regarding sex before marriage and ending a life. Religious people (historically) take in a less accepting stance towards matters such as abortion (FIOM, n.d.-a). Therefore, religion increases stigma around pregnancy. Additionally, religion influences the feelings towards abortion and feelings towards adoption. As stated, abortions are perceived to be less accepted. Thus, the feelings towards having an abortion are negatively influenced by religion. Moreover, when a woman does not want to keep the baby, the clergyman is more likely to advise her to put the baby up for adoption. Hence, when a woman has spoken to the clergyman, she has gained advice on the matter.

Plasticity and metaplasticity Due to the many described influences it can be difficult to make a decision. The process of learning and decision making, according to neurosciences, happens in response to a stimulus (e.g., information). Subsequently, the responding and predicting connections in the brain, based on which a decision is made, are adaptive; an example of this adaptivity (also called *plasticity*), is Hebbian learning (Hebb, 1949), in a simplified form formulated as:

'Neurons that fire together, wire together' (Shatz, 1992)

However, when a person – in this case a pregnant woman – learns about her possible options, she does this at different times and speed. As a form of control the learning speed is also adaptive, which makes the occurrence of the learning process itself dependent on contextual circumstances. This is called *metaplasticity*; e.g., (Abraham and Bear, 1996; Robinson, Harper, McAlpine, 2016). The following is an example of a metaplasticity principle:

'Adaptation accelerates with increasing stimulus exposure' (Robinson et al., 2016)

Principles of plasticity and metaplasticity have been applied in the introduced adaptive decision model regarding proceeding with a pregnancy, having an abortion or putting the baby up for adoption. As a result, such a model can be used to better understand the learning effect of information sources on the decision-making process of a woman.

3 Description of the Second-Order Adaptive Decision Model

For the decision-making process of this model, a second-order adaptive network model was designed. The model describes the influences of different factors and the influence of talking to different actors over time. When being pregnant, different factors influence the decision to proceed with or terminate the pregnancy. By using a Hebbian Learning process, the influences of the (f)actors can be strengthened or weakened and therefore they can influence the decision-making process.

The conceptual representation of the causal network model consists of states and connections between the states. These connections can represent a causal impact. It is assumed that the states have activation levels that vary over time. Adaptation of causal relations and other network characteristics are incorporated in the approach too (Treur, 2020). The network structure characteristics used are as follows:

Connectivity of the network Connection weights $\omega_{X,Y}$ for each connection from a state (or node) X to a state Y .

Aggregation of multiple impacts A combination function $c_Y(..)$ for each state Y to determine the aggregation of incoming causal impacts.

Timing in the network A speed factor η_Y for each state

Moreover, self model states (also called reification states) were added to the network to make some of the network characteristics adaptive. For this model, states $\mathbf{W}_{X,Y}$ and $\mathbf{H}_{X,Y}$ were used. The \mathbf{W} -states $\mathbf{W}_{X,Y}$ are first-order self-model states; they represent their complementary connection weight $\omega_{X,Y}$. Additionally, in this model there are five second-order self-model states $\mathbf{H}_{W_{X,Y}}$ representing the timing (speed factor) characteristic $\eta_{W_{X,Y}}$ for the mentioned first-order self model states $\mathbf{W}_{X,Y}$. Adding these speed factors allowed for determining the moment when each of the learning activities would take place. In this way, metaplasticity of the model was ensured.

Connection weights normally have values between 0 and 1. However, when the connection has a suppressing effect, it also can be negative. For the model of this study, connection weights with values between -1 and 1 are used. The states with a positive impact in the base level are: education (X_1), partner (X_2), religion (X_4), obtaining education (X_6), total income (X_7), fear (X_9), stigma (X_{11}), lack of knowledge (X_{12}), feelings towards keeping the baby (X_{13}), feelings towards not keeping the baby (X_{15}), feelings towards abortion (X_{16}), and feelings towards adoption (X_{18}). States with negative impact in the base level are: planned or wanted pregnancy (X_8), fear (X_9), decision to keep the baby (X_{14}), decision to have an abortion (X_{17}), and decision to start the adoption process (X_{19}).

The influence of the states social network (X_3) on stigma (X_{11}), expert (X_5) on lack of knowledge (X_{12}), opinion partner (X_{10}) on stigma (X_{11}), religion (X_4) on feelings towards abortion (X_{16}), and religion (X_4) on feelings towards adoption (X_{18}) are adaptive and therefore discussed in the next section. States X_1 until X_6 have no incoming connections as these represent the individual factors of a pregnant woman. They do influence other states in the model. Total income of the woman (X_7) is positively influenced by education (X_1) and partner (X_2). Both connections have positive connection weights $\omega_{X,Y}$ of weight 1, as being highly educated and having a stable relationship have a positive effect on the total income of a woman. In addition, opinion partner (X_{10}) also has a positive incoming connection ($\omega_{X,Y}=1$) from partner

(X₂). To indicate, when there is a stable relationship with a partner, the partner has an opinion about the pregnancy which influences the decision process. Planned or wanted pregnancy (X₈) is positively ($\omega_{X,Y}=1$) influenced by total income (X₇). For instance, when the total income of a pregnant woman is high, the pregnancy is more likely to be planned.

Stigma (X₁₁) is positively influenced ($\omega_{X,Y}=1$) by religion (X₄) as religion can cause or enhance stigma around topics such as pre-marital sex and abortion. Stigma (X₁₁) itself has a positive influence ($\omega_{X,Y}=1$) on the lack of knowledge (X₁₂), as stigma is expected to be a dominant factor compared to knowledge. Hereafter, lack of knowledge (X₁₂) has a positive effect ($\omega_{X,Y}=1$) on fear (X₉). For example, when there is much stigma around a pregnancy and there is a lack of knowledge about pregnancy options, a woman will develop fear around the pregnancy. However, fear (X₉) is negatively influenced ($\omega_{X,Y}=-0.5$) by planned or wanted pregnancy (X₈). A woman who planned or wants a pregnancy is less likely to have fear regarding the pregnancy and therefore the connection is negative.

Fear (X₉) has a negative influence ($\omega_{X,Y}=-0.5$) on the feelings towards keeping the baby (X₁₃). However, partner (X₂) has a positive influence ($\omega_{X,Y}=-0.5$) on the feelings towards keeping the baby (X₁₃). When having fear for the pregnancy, the women will more likely feel negative towards keeping the baby (and therefore positive towards not keeping the baby (X₁₅)). Therefore, this influence is negative. Based on literature, having a partner is the biggest reason to keep the baby during a pregnancy (see Section 2). Therefore, this influence is positive. As mentioned in the above paragraph, fear (X₉) has a positive impact on the feelings towards not keeping the baby (X₁₅). Subsequently, the feelings towards not keeping the baby (X₁₅) have positive influences on the feelings towards abortion (X₁₆) and adoption (X₁₈). Both with a connection weight of 1.

Lastly, all decision states (X₁₄, X₁₇, and X₁₉) are positively influenced ($\omega_{X,Y}=1$) by the feeling states (X₁₃, X₁₆, and X₁₈). All decision states are mutually exclusive towards each other and therefore there are negative connections ($\omega_{X,Y}=-0.6$) between them. An overview of the states, the names, an explanation and the incoming connections can be found in the Appendix as Linked Data at

<https://www.researchgate.net/publication/357372192>.

In this model, there are five first-order self-model states that model the learning process. Together, they represent the actor-network which a pregnant woman uses to gain information to help her with the decision-making process. Thus, as she gains the information through interaction, she learns more about the subject by strengthening the connections involved. To start, the influence of a (supportive) social network (X₃) on stigma (X₁₁) is incorporated in the model (X₂₀ = **W**_{Social network, Stigma}). As described, after a woman speaks with her supportive social network, she is offered support, knowledge and acceptance, which in turn lowers the stigma. Therefore, this **W**-state models adaptivity of the negative effect on the base level state stigma. Secondly, the adaptive negative influence of experts (X₅) on lack of knowledge (X₁₂) is incorporated through X₂₁ (= **W**_{Experts, Lack of knowledge}). By providing the woman with more expert information, she gains knowledge about the subject (the connection strengthens), thereby decreasing the lack of knowledge. Thirdly, the opinion of the partner (X₁₀) has a positive influence on stigma (X₁₁).

This learning relation is modelled by means of X₂₂ (**W**_{Opinion partner, Stigma}). Due to the previously described gender-inequality in the Netherlands, the opinion of the partner is

believed to enhance the stigma. Lastly, there is a large influencing role of religion (X_4) on the feelings towards abortion (X_{16}) and feelings towards adoption (X_{18}). These respectively negative and positive connections are translated in X_{23} ($= \mathbf{W}_{\text{Religion, Feelings towards abortion}}$) and X_{24} ($= \mathbf{W}_{\text{Religion, Feelings towards adoption}}$). For all described adaptive states in the first level (X_{20} - X_{24}), the influence of the actor becomes clear after the woman has interacted with them and this has activated a learning process for the connection involved.

Complementary to the connection weight self-model states (the \mathbf{W} -states) are the speed factor self-model states (the \mathbf{Hw} -states) in the second self-model level. The five \mathbf{Hw} -states (X_{25} - X_{29}) determine the speed and time of the learning from an interaction between each of the actors and the woman. This has been done by a variation on the principle of metaplasticity mentioned in Section 2:

‘Adaptation accelerates with increasing stimulus exposure’ (Robinson et al., 2016)

Such a principle makes the extent of adaptation context-dependent, depending on environmental circumstances. In this case, the social environment is chosen as what triggers the adaptation. This social environment makes that in certain time periods interaction takes place with certain persons. Exactly this is modeled by activation of the \mathbf{Hw} -states as a form of activation of such social interactions. This means that the learning occurs, when such periods take place. An overview of the \mathbf{W} -states and \mathbf{Hw} -states of the model and their description can be found in Appendix as Linked Data at <https://www.researchgate.net/publication/357372192>. Similar to the states of the base level, self-model states can be defined by three network characteristics: connectivity, aggregation and timing. This knowledge can be translated to the network model (Fig. 1). The connectivity, in terms of incoming and outgoing connections of the self-model state has different functions. First, the outgoing downward causal connections (pink arrows in Fig. 1) from the self-model states representing a causal impact from the specific role (also indicated in the name).

This for example means that in the presented model the connection of $\mathbf{Hw}_{X_3, X_{11}}$ is used for the adaptation speed of the weight of the connection from X_3 on X_{11} . Second, the upward causal connections (blue arrows in Fig. 1) towards the self-model states give the self-model states the dynamic characteristic as desired. They specify the adaptation principle that is addressed, together with the combination function and the downward connection.

By the use of *role matrices*, the network characteristics $\omega_{X,Y}$, $\mathbf{c}_Y(\cdot)$, η_Y that define a network model can be specified in a concise and structured way which is also readable by the dedicated software environment. There are five different types of role matrices and each role matrix shows the data of a specific type. Role matrix \mathbf{mb} for the base connectivity of the network, \mathbf{mcw} for the specific connection weights, \mathbf{ms} for the speed factors, \mathbf{mcfw} for the combination functions used with their weights, and \mathbf{mcfp} for the parameters of these combination functions (Treur, 2020). The complete specified conceptual representation of the network model by role matrices can be found in the Appendix as Linked Data at <https://www.researchgate.net/publication/357372192>.

For the numerical representation of the model, a standard canonical difference or differential equation is used:

$$Y(t + \Delta t) = Y(t) + \eta_Y [\mathbf{aggimpact}_Y(t) - Y(t)] \Delta t \quad (1)$$

$$\mathbf{d}Y(t)/\mathbf{d}t = \eta_Y [\mathbf{aggimpact}_Y(t) - Y(t)]$$

where X_1, \dots, X_k are the states from which Y gets incoming connections and

$$\mathbf{aggimpact}_Y(t) = \mathbf{c}_Y(\mathbf{impact}_{X_1,Y}(t), \dots, \mathbf{impact}_{X_k,Y}(t))$$

with $\mathbf{impact}_{X_i,Y}(t) = \omega_{X_i,Y} X_i(t)$

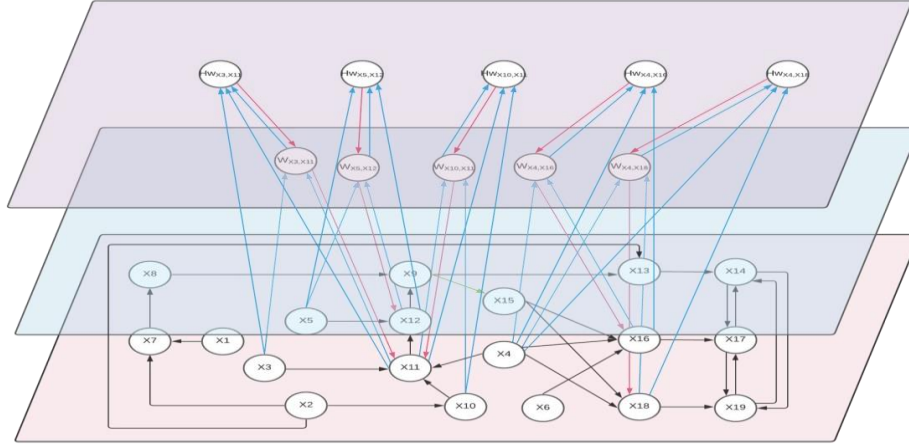


Fig. 1 Overview of the conceptual representation of the model: base level, first self-model level and second self-model level.

By using the combination function \mathbf{c}_Y , the aggregated causal impact of multiple states X_i on Y at time point t is determined (Treur, 2016, 2020). The aggregated causal impact on Y , is applied gradually over time by using (and in proportion with) the speed factor η_Y . A dedicated software environment developed in Matlab is available by which the conceptual design representation of a network model is transformed into a numerical design representation. This numerical design description can be used for simulation.

In Matlab, there are different combination functions available in the library. These combination functions can be used to express the desired effect of the impact on the states (Treur, 2020). The combination functions, including their description, formula, and parameters, used in the model are shown in Table 1.

Table 1 Overview of the Combination Functions used for the model

Name	Description	Formula	Parameters	Used for
alogistic $f, l(V_1, \dots, V_k)$	Advanced logistic sum	$\frac{1}{1 + e - \sigma(V_1 + \dots + V_k - \tau)}$ $- \frac{1}{1 + e^{\sigma\tau}}(1 + e^{-\sigma\tau})$	Steepness σ Threshold τ	$X_1 - X_{19}$
hebb$_{\mu}$ (V_1, V_2, W)	Hebbian learning: positive weights	$V_1 V_2 (1 - W) + \mu W$	Persistence factor μ	X_{22}, X_{24}
hebbneg$_{\mu}$ (V_1, V_2, W)	Hebbian learning: negative weights	$-V_1 (1 - V_2) (1 + W) + \mu W$	Persistence factor μ	X_{20}, X_{21}, X_{23}
steponce$_{\alpha, \beta}(\dots)$	Activation for period from α to β	1 if $\alpha \leq t \leq \beta$, else 0 (time t)	Start time α End time β	$X_{25} - X_{29}$

4 Simulation Results

In this section, three different simulations for three different scenarios are shown; keeping the baby, having an abortion and putting the baby up for adoption. For each simulation (and scenario), different combinations of initial values (iv's) are chosen as presented in Table 2. Here, the iv's of states X_1 to X_6 have different values for each scenario as these are the states without incoming connections and represent factors which are scenario specified. In the following paragraphs, the simulations will be shown by first explaining the scenario and iv's. Thereafter, the graphs of the simulations will be shown and interesting states will be discussed. And finally, it is discussed which decision is made.

Table 2 initial values for the states for three different simulations (Sim).

State	Sim. 1	Sim. 2	Sim. 3	State	Sim. 1	Sim. 2	Sim. 3
X_1	1	1	0.5	X_{16}	0	0	0
X_2	1	0.5	1	X_{17}	0	0	0
X_3	1	1	0.5	X_{18}	0	0	0
X_4	0	0	1	X_{19}	0	0	0
X_5	1	1	0.1	X_{20}	0.5	0.5	0.5
X_6	0.5	1	0.1	X_{21}	0.5	0.5	0.5
X_7	0	0	0	X_{22}	0.5	0.5	0.5
X_8	0	0	0	X_{23}	0.5	0.5	0.5
X_9	0	0	0	X_{24}	0.5	0.5	0.5
X_{10}	0	0	0	X_{25}	0	0	0
X_{11}	0	0	0	X_{26}	0	0	0
X_{12}	1	1	1	X_{27}	0	0	0
X_{13}	0	0	0	X_{28}	0	0	0
X_{14}	0	0	0	X_{29}	0	0	0
X_{15}	0	0	0				

Simulation 1: Keeping the baby In simulation Scenario 1, the initial values (iv) as shown in Table 2 were used. They indicate the scenario of a pregnant woman who is highly educated (iv = 1), has a stable relationship with a male partner (iv = 1), has a supportive network of family and friends (iv = 1), does not attend religious services (iv = 0), talks to an expert in the field (iv = 1) and part-time obtains education (iv = 0.5). Fig. 2 shows the outcome of the simulation. Note that to improve the clarity and visibility, states X_1 - X_6 and X_{20} - X_{24} are not depicted. As can be observed, the decision to keep the baby (X_{14}) is more dominant compared to the decision for having an abortion (X_{17}) or an adoption (X_{19}). Furthermore, the influence of $\mathbf{H}_{\text{Opinion partner, Stigma}}$ (X_{27}) via $\mathbf{W}_{\text{Opinion partner, Stigma}}$ on stigma (X_{11}) is slightly positive. The value of stigma (X_{11}) increases after $t = 10$ which may be due to the positive impact of opinion partner (X_{10}) on stigma (X_{11}). However, stigma (X_{11}) lowers again after the influence of $\mathbf{H}_{\text{Social network, Stigma}}$ (X_{25}) via $\mathbf{W}_{\text{Social network, Stigma}}$. This leads to the second interesting observation of this simulation: the influence of $\mathbf{H}_{\text{Social network, Stigma}}$ (X_{25}) on the base level states. At $t = 30$, the feelings towards abortion (X_{16}) and the decision to have an abortion (X_{17}) were higher compared to the feelings towards keeping the baby (X_{13}) and the decision to keep the baby (X_{14}).

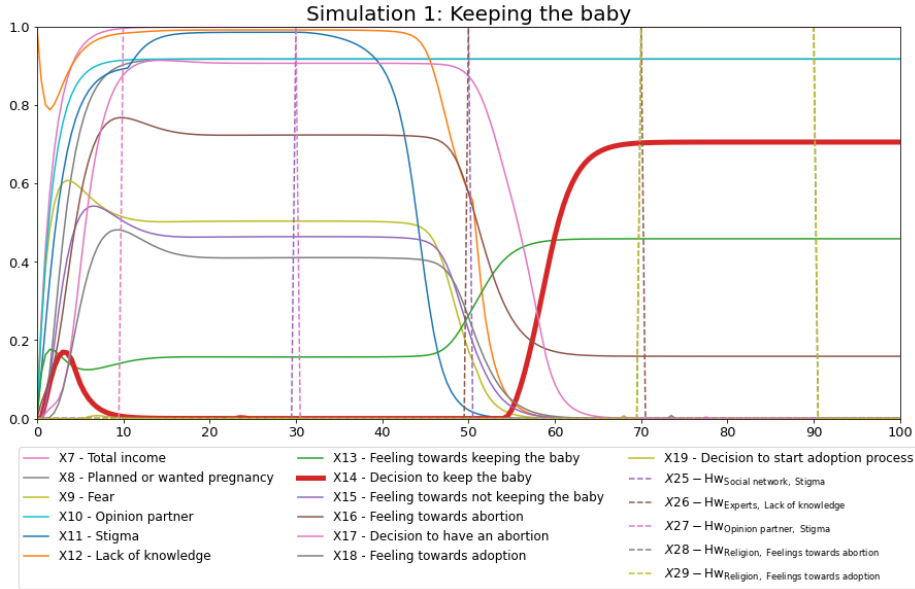


Fig. 2 Simulation for Scenario 1: keeping the baby. Graph: left out X_1 - X_6 and X_{20} - X_{24}

However, during the period of $t = 40$ until $t = 50$, stigma (X_{11}), lack of knowledge (X_{12}), and fear (X_9) decreased much. Therefore, the feelings towards abortion (X_{16}) and the decision to have an abortion (X_{17}) decreased and subsequently the feelings to keep the baby (X_{13}) increased. Additionally, due to the influence of $H_{wExperts, Lack\ of\ knowledge}$ (X_{26}) at $t = 50$ via $W_{Experts, Lack\ of\ knowledge}$, the feelings towards abortion (X_{16}), the decision to have an abortion (X_{17}), stigma (X_{11}), lack of knowledge (X_{12}), and fear (X_9) also decreased. Whereas the feelings towards keeping the baby (X_{13}) and the decision to keep the baby (X_{14}) increased. Hereafter, $H_{wReligion, Feelings\ towards\ abortion}$ (X_{28}) and $H_{wReligion, Feelings\ towards\ adoption}$ (X_{29}) showed limited effect. This can be explained as the initial value of religion (X_4) was set at 0. Hence, the decision to keep the baby (X_{14}) wins.

Simulation 2: Abortion For Scenario 2, the initial values indicate a pregnant woman who is highly educated ($iv = 1$), in an unstable relationship with a male partner ($iv = 0.5$), has a supportive network of family and friends ($iv = 1$), not attending religious services ($iv = 0$), talking to an expert in the field ($iv = 1$) and is still obtaining education ($iv = 1$). Fig. 3 shows the results of the second simulation, again without the states that hinder visibility. As shown in Fig. 3, the decision to have an abortion (X_{17}) was more dominant compared to the decision for an adoption (X_{19}) or keeping the baby (X_{14}). This can be explained by looking at the different factors and the adaptive influences of the actors over time. Starting with the influences of $H_{wOpinion\ partner, Stigma}$ (X_{27}) via $W_{Opinion\ partner, Stigma}$ on the base level states, it can be seen that after $t = 10$, stigma (X_{11}) obtained a higher value. This can be explained by the positive effect of the opinion of the partner (X_{10}) on stigma (X_{11}). Second, the influence of $H_{wSocial\ network, Stigma}$ (X_{25}) after $t = 30$ via $W_{Social\ network, Stigma}$ caused stigma (X_{11}) to lower due to the negative effect of the social network (X_3) on stigma (X_{11}).

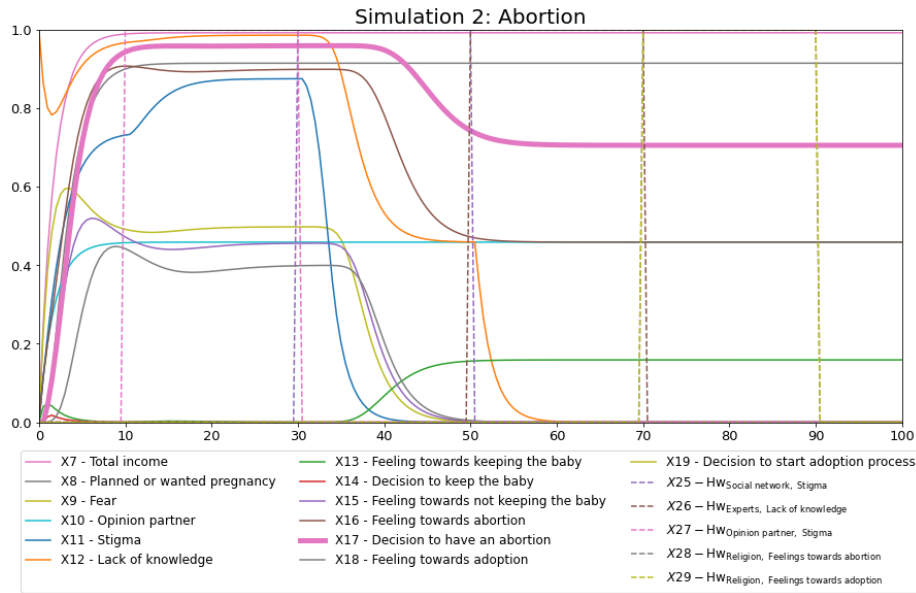


Fig. 3 Simulation for Scenario 2: Abortion. Graph: left out X_1 - X_6 and X_{20} - X_{24} .

Furthermore, stigma (X_{11}) had a direct influence on the lack of knowledge (X_{12}) and therefore an indirect influence on fear (X_9). Subsequently, the values of lack of knowledge (X_{12}) and fear (X_9) lowered, which resulted in increased feelings towards not keeping the baby (X_{13}). Thirdly, $H_{w}^{\text{Experts, Lack of Knowledge}}$ (X_{26}) between $t = 50$ and $t = 70$ resulted in a decreased lack of knowledge (X_{12}). Hence, the decision to have an abortion (X_{17}) slightly decreased. However, the decision to have an abortion (X_{17}) remained dominant due to the suppression on the decision to keep the baby (X_{14}) and the decision to start the adoption process (X_{19}). Lastly, $H_{w}^{\text{Religion, Feelings towards abortion}}$ (X_{28}), and $H_{w}^{\text{Religion, Feelings towards adoption}}$ (X_{29}) showed no influence on the states, which can be explained as the initial value of religion (X_4) was set at 0.

Simulation 3: Adoption In simulation Scenario 3, the initial values indicate the scenario of a pregnant woman who is averagely educated ($iv = 0.5$), has a stable relationship with a male partner ($iv = 1$), has a semi-supportive network of family and friends ($iv = 0.5$), attends religious services ($iv = 1$), hardly speaks with an expert ($iv = 0.1$) in the field and not really obtains education ($iv = 0.1$). Fig. 4 shows the results of the last simulation, again without the states that hinder visibility. In the figure it can be seen that $H_{w}^{\text{Opinion partner, Stigma}}$ (X_{27}) had a small positive effect on the feelings towards not keeping the baby (X_{15}). Moreover, $H_{w}^{\text{Opinion partner, Stigma}}$ (X_{27}) showed a decreasing effect on the feelings towards keeping the child (X_{13}). $H_{w}^{\text{Social network, Stigma}}$ (X_{25}) and $H_{w}^{\text{experts, Lack of knowledge}}$ (X_{26}) did not have a strong influence on the base-level states, except for lack of knowledge (X_{12}) which lowered at $t = 50$ due to the influence of $H_{w}^{\text{experts, Lack of knowledge}}$ (X_{26}).

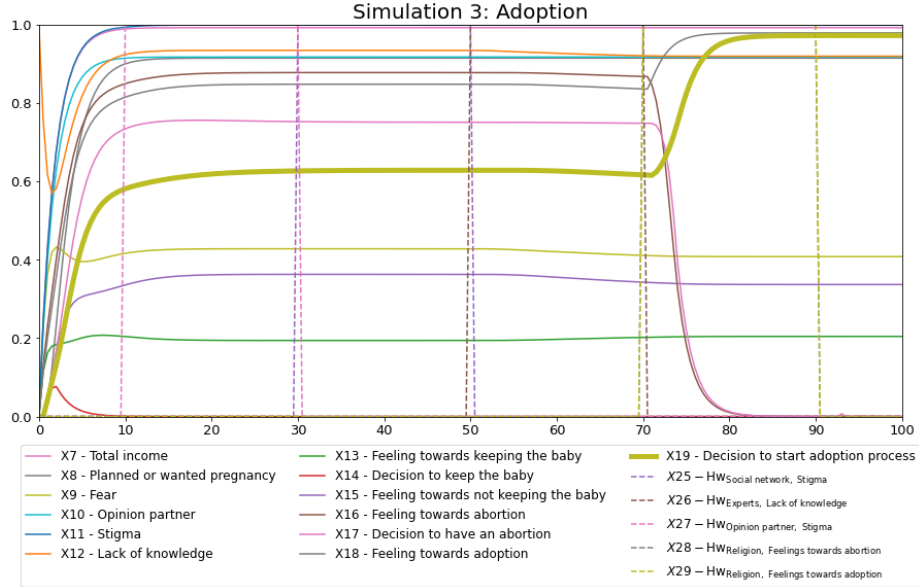


Fig. 4 Simulation for Scenario 3: Adoption. Graph: not displaying X_1 - X_6 and X_{20} - X_{24}

However, due to the initial value of religion (X_4) there are some interesting increases and decreases visible between $t = 70$ and $t = 90$. Before $t = 70$, the feelings towards abortion (X_{16}) were higher compared to the feelings towards an adoption (X_{18}) and the feelings towards keeping the child (X_{13}). However, after $t = 70$ the input of state $\mathbf{HwReligion}$, Feelings towards abortion (X_{28}) resulted in a negative impact on feelings towards abortion (X_{16}) and the decision to have an abortion (X_{17}) via $\mathbf{WReligion}$, Feelings towards abortion. Moreover, $\mathbf{HwReligion}$, Feelings towards adoption (X_{29}) had a positive influence via $\mathbf{WReligion}$, Feelings towards adoption on the feelings towards an adoption (X_{18}) and subsequently on the decision to have an adoption (X_{19}). Hence, due to the influences of $\mathbf{HwReligion}$, Feelings towards abortion (X_{28}) and $\mathbf{HwReligion}$, Feelings towards adoption (X_{29}) the feeling towards abortion (X_{16}) decreased and the feeling towards an adoption (X_{18}) increased. Therefore, the decision to start the adoption process (X_{19}) won.

5 Discussion

The aim of this paper was to understand the influences of various information sources on the decision-making process regarding keeping or not keeping a baby. To accomplish this, a second-order adaptive temporal-causal decision model was created. Hereby, various factors and actors influencing the decision-making process were represented. By including adaptive connections and speed factors, the model was able to simulate dynamic real-life situations. As a result, the model consists of adaptive learning cycles which may influence over a certain period of time the development of the end decision of the pregnant women. For the purpose of this research, three different scenarios were simulated visualising the influence of four actors on the decision-

making process. In this way, adaptiveness in terms of both how the model learns (plasticity) and at what speed and time (metaplasticity) for the decision process was modelled. Thus, this model contributed to the current knowledge base by illustrating how the process for a pregnant woman making a decision to either keep or not keep a baby can be influenced over time by different actors.

The model was mathematically verified and validated by means of parameter tuning; see the Appendix as Linked Data at URL

<https://www.researchgate.net/publication/357372192>.

Additionally, as the context of the model was a logical and real-world process, researcher biases could have influenced the design of the model. What was seen as a logical time span and order, was partly derived from literature, but may also have been influenced by views, interpretations and visions of the researchers themselves. However, the evidence from literature was, to the best of the researchers' knowledge, generalised for this model. Nevertheless, the decision-making process for keeping or not keeping a baby is very personal and context-dependent as with many real world processes. Therefore, it is an open question whether this model will comply with every pregnant woman in the world.

For future research it is thus recommended to seek more empirical data regarding the timing of influences of the different actors to substantiate and improve the model. This can be done by more extensive literature review or by conducting own qualitative or quantitative research regarding the decision-making process. Secondly, as the model makes use of the person dependent factors ($X_1 - X_6$) that may vary for every person, it can be further adapted to fit the context. For example, the model can also be altered to accommodate different cultures or individuals. Lastly, for future research it would be interesting to include more factors by adding more states to the model. In our research we only included 19 factors in the base level, 5 in the first-order, and 5 in the second-order self-model level. However, there are more factors which (possibly) influence the process that can be included in the model for a wider coverage.

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