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Chapter 7
A Controlled Adaptive Self-modeling Network Model of Multilevel Organisational Learning for Individuals, Teams or Projects, and Organisation

Gülay Canbaloğlu, Jan Treur, and Peter H. M. P. Roelofsma

Abstract Multilevel organisational learning concerns an interplay of different types of learning at individual, team, and organisational levels. These processes use complex dynamic and adaptive mechanisms. A second-order adaptive network model for this is introduced here and illustrated.

Keywords Multilevel organisational learning · Adaptive network model · Self-model

7.1 Introduction

Multilevel organisational learning is a complex, dynamic, adaptive, cyclical and non-linear type of learning involving multiple levels and both dependent on individuals and independent of individuals. It is multilevel because the learning of an organisation involves learning at the level of individuals, at the level of teams (or groups or projects), and at the level of the organisation via feed forward and feedback pathways:

> Through feed-forward processes, new ideas and actions flow from the individual to the group to the organisation levels. At the same time, what has already been learned feeds back from the organisation to group and individual levels, affecting how people act and think. (Crossan et al. 1999), p. 532.
>
> 'There is growing consensus in the literature that the theory of organisational learning should consider individual, team and organisational levels' (Wiewiora et al. 2019), p. 94

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There is a huge amount of literature on multilevel organisational learning such as (Argyris and Schön 1978; Bogenrieder 2002; Crossan et al. 1999; Fischhof and Johnson 1997; Kim 1993; McShane and Glinow 2010; Stelmaszczyk 2016; Wiewiora et al. 2019; Wiewiora et al. 2020). However, until recently systematic approaches to obtain (adaptive) computational models were not easy to find. In the current chapter, a self-modeling network modeling perspective is used to model the different adaptive, interacting processes of multilevel organisational learning. In contrast to the previous Chap. 6 of this volume (Canbaloğlu et al. 2023b), in the current chapter also the intermediate level of teams or projects is addressed, following (Crossan et al. 1999; Wiewiora et al. 2019) whereas in the previous chapter the paper of Kim (1993) was used as a main source of inspiration, where this intermediate level is not addressed.

Computational modeling of multilevel organisational learning provides a more observable formalization of multilevel organisational learning and provides possibilities to perform 'in silico' (simulation) experiments with it. To this end, the self-modeling network modeling approach introduced in (Treur 2020) that is explained in some detail in Sect. 7.3, is used in this current chapter.

First, Sect. 7.2 presents how literature provides ideas on mental models at individual, team and organisation level and their role in multilevel organisational learning. Then, Sect. 7.3 explains the characteristics and details of adaptive self-modeling network models and how they can be used to model the different processes concerning dynamics, adaptation and control of mental models. In Sect. 7.4 the controlled adaptive network model for multilevel organisational learning is introduced. Then in Sect. 7.5, an example simulation scenario is explained in detail. Section 7.6 is a Discussion section.

7.2 Background Literature

The quotes in the introduction section illustrate the perspective adopted here. Mental models are considered a vehicle to model the interplay of learning at individual, team and organisational level. Individual mental models learnt are a basis for formation of shared team mental models; these shared team mental models provide input for the shared mental models at the organisation level. Conversely, these shared mental models at organisation and team level are used to improve shared team mental models and individual mental models, respectively. The picture of the different pathways shown in Fig. 7.1 is based on Fig. 4 of Wiewiora et al. (2019) and Fig. 3 of Wiewiora et al. (2020).

Inspired by this, as a basis for the analysis made here, the considered overall multilevel organisational learning process consists of the following main pathways and interactions; see also Crossan et al. (1999) and Wiewiora et al. (2019):

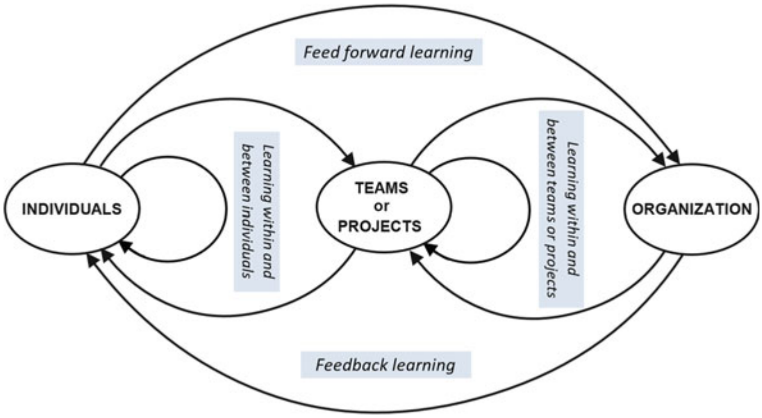

Fig. 7.1 Multilevel organisational learning: multiple levels and nested cycles (with depth 3) of interactions; see also Wiewiora et al. (2019) and Wiewiora et al. (2020)

(a) **Individual level**

(1) Creating and maintaining individual mental models
(2) Choosing for a specific context a suitable individual mental model as focus
(3) Applying a chosen individual mental model for internal simulation
(4) Improving individual mental models

(b) **From individual level to team level (feed forward learning)**

(1) Deciding about creation of shared team mental models
(2) Creating shared team mental models based on developed individual mental models

(c) **From team level to organisation level (feed forward learning)**

(1) Deciding about creation of shared mental models
(2) Creating shared mental models based on developed individual mental models

(d) **From organisation level to team level (feedback learning)**

(1) Deciding about teams to adopt shared organisation mental models
(2) Teams adopting shared mental models

(e) **From team level to individual level (feedback learning)**

(1) Deciding about individuals to adopt shared team mental models
(2) Individuals adopting shared team mental models by learning them

(f) **Individual level**

(1) Creating and maintaining individual mental models
(2) Choosing for a specific context a suitable individual mental model as focus

(3) Applying a chosen individual mental model for internal simulation
(4) Improving individual mental models

This overview provided useful input to the design of the computational network model for multilevel organisational learning that will be introduced in Sect. 7.4.

7.3 The Self-modeling Network Modeling Approach

In this section, the self-modeling network modeling approach (Treur 2020) used is explained in some detail. A network model is defined by (where X and Y are nodes or states of the network):

- *Connectivity characteristics*
  Connections from one state X to a state Y with their weights $\boldsymbol{\omega}_{X,Y}$
- *Aggregation characteristics*
  For any state Y, a combination function $\mathbf{c}_{\boldsymbol{Y}}\mathbf{(..)}$ is used to specify the aggregation that is applied to the impacts $\boldsymbol{\omega}_{X,Y}X(t)$ on Y from the incoming connections from states X to Y
- *Timing characteristics*
  For each state Y a speed factor $\boldsymbol{\eta}_Y$ defines how fast it changes for given causal impact.

Each state or node Y has time t dependent activation values $Y(t)$. The following difference equations are used for simulation; they are based on the network characteristics $\boldsymbol{\omega}_{X,Y}$, $\mathbf{c}_Y(..)$, $\boldsymbol{\eta}_Y$ in a canonical manner:

$$Y(t + \Delta t) = Y(t) + \boldsymbol{\eta}_Y[\mathbf{c}_Y(\boldsymbol{\omega}_{X_1,Y}X_1(t), \ldots, \boldsymbol{\omega}_{X_k,Y}X_k(t)) - Y(t)]\Delta t \qquad (7.1)$$

for each state Y, where X_1 to X_k are the states from which Y receives incoming connections. The dedicated software environment (Treur 2020, Chap. 9), includes a library with currently around 70 basic combination functions. The examples of basic combination functions that are applied in the model introduced here can be found in Table 7.1.

By using a *self-modeling principle* (also called a *reification principle*), a network-oriented conceptualisation can also be applied to *adaptive* networks; see (Treur 2020). Here new states are added to the network (called *self-model states*) representing network characteristics. These self-model states are depicted at a next level (called *self-model level* or *reification level*); the original network is at the *base level.*

This is often applied to the weight $\boldsymbol{\omega}_{X,Y}$ of a connection from state X to state Y; this is represented by a self-model state $\mathbf{W}_{X,Y}$. Similarly, any other network characteristic from $\boldsymbol{\omega}_{X,Y}$, $\mathbf{c}_Y(..)$, $\boldsymbol{\eta}_Y$ can be self-modeled by including self-model states. For example, the speed factor $\boldsymbol{\eta}_Y$ of a state Y can be represented by a self-model state $\mathbf{H}_Y$.

This self-modeling network construction can be applied iteratively to obtain multiple orders of self-models at multiple (first-order, second-order, …) self-model

Table 7.1 The combination functions applied in the introduced network model

	Notation	Formula	Parameters
Advanced logistic sum	$\textbf{alogistic}_{\sigma,\tau}(V_1, \ldots, V_k)$	$[\frac{1}{1+e^{-\sigma(V_1+\cdots+V_k-\tau)}} - \frac{1}{1+e^{\sigma\tau}}](1 + e^{-\sigma\tau})$	Steepness $\sigma > 0$ Excitability threshold τ
Steponce	$\textbf{steponce}_{\alpha,\beta}(..)$	1 if time t is between α and β, else 0	Start time α End time β
Hebbian learning	$\textbf{hebb}_{\mu}(V_1, V_2, V_3)$	$V_1 * V_2(1 - V_3) + \mu V_3$	V_1,V_2 activation levels of states X and Y; V_3 activation level of the self-model state $\mathbf{W}_{X,Y}$ Persistence factor μ
Maximum composed with Hebbian learning	$\textbf{max-hebb}_{\mu}(V_1, \ldots, V_k)$	$\max(\textbf{hebb}_{\mu}(V_1, V_2, V_3), V_4, \ldots, V_k)$	
Scaled maximum	$\textbf{smax}_{\lambda}(V_1, \ldots, V_k)$	$\max(V_1, \ldots, V_k)/\lambda$	Scaling factor λ

levels. For example, a second-order self-model may include a second-order self-model state $\mathbf{H}_{\mathbf{W}_{X,Y}}$ representing the speed factor $\eta_{\mathbf{W}_{X,Y}}$ for the (learning) dynamics of first-order self-model state $\mathbf{W}_{X,Y}$ which in turn represents an adaptative connection weight $\omega_{X,Y}$. Similarly, a persistence factor $\mu_{\mathbf{W}_{X,Y}}$ of such a first-order self-model state $\mathbf{W}_{X,Y}$ used for adaptation (e.g., based on Hebbian learning) can be represented by a second-order self-model state $\mathbf{M}_{\mathbf{W}_{X,Y}}$.

In the current chapter, the self-modeling network perspective is applied to design a second-order adaptive mental network architecture addressing the mental and social processes underlying organisational learning by proper handling of individual mental models and shared mental models. In this self-modeling network architecture, the base level addresses the use of a mental model by internal simulation, the first-order self-model the adaptation of the mental model, and the second-order self-model level models the control over this; see Fig. 7.2. In this way the three-level cognitive architecture described in (Van Ments et al. 2021; Treur and Van Ments 2022) is formalized computationally in the form of a self-modeling network architecture. In Bhalwankar and Treur (2021) it is shown how specific forms of learning and their control can be modeled based on this self-modeling network architecture, in particular learning by observation and learning by instruction and combinations thereof (Yi and Davis 2003; Van Gog et al. 2009). Some of these forms of learning will also be applied in the model for multilevel organisational learning introduced here in Sect. 7.4.

7.4 The Network Model for Multilevel Organisational Learning

In the considered case study concerning tasks a, b, c, and d, initially the individual mental models of 4 people are different and based on some strong and some weak

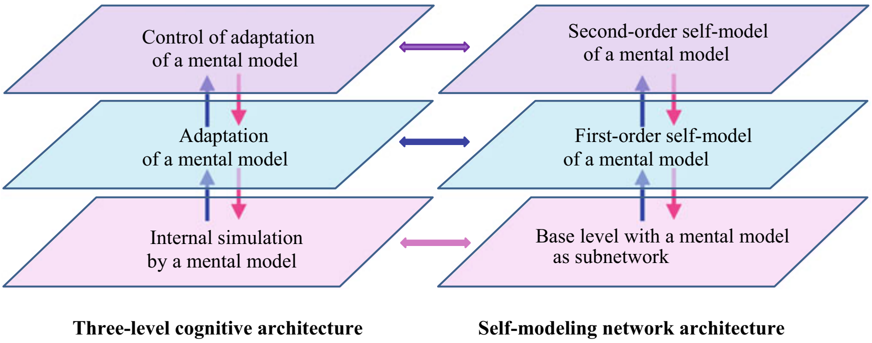

Fig. 7.2 Computational formalization of the three-level cognitive architecture for mental model handling from (Treur and Van Ments 2022) by a self-modeling network architecture

connections; they don't use a stronger shared mental model as that does not exist yet. The multilevel organisational learning addressed to improve the situation covers:

1. Individual (Hebbian) learning by persons of their mental models through internal simulation which results in stronger but still incomplete and different mental models. Person A and C's mental models have no connection from task *c* to task *d* and person B and D's mental models have no connection from *a* to *b*.
2. Formation of two shared team mental models for teams T1 (consisting of persons A and B) and T2 (consisting of persons C and D) based on the different individual mental models. A process of unification by aggregation takes place (feed forward learning).
3. Formation of a shared organisation mental model based on the two team mental models. Again, a process of unification by aggregation takes place (feed forward learning).
4. Flow of information and knowledge from organisation mental model to team mental models, e.g., a form of instructional learning (feedback learning).
5. Learning of individual mental models from the shared team mental models, e.g., also a form of instructional learning (feedback learning).
6. Improvements on these individual mental models by individual learning through internal simulation which results in stronger and now complete mental models (by Hebbian learning). Now person A and C's mental models have a connection from task c to task d, and person B and D's mental models have a connection from a to b.

The connectivity of the introduced network model is shown in Fig. 7.3 to Fig. 7.6; for an overview of the states, see Figs. 7.7, 7.8, 7.9, 7.10 and 7.11, and for more details about the connections and how they relate to **(a)**–**(f)** from Sect. 7.2, see Fig. 7.12.

The undermost base level of this model has mental model states for individuals, teams and organisation, and also context states for activation of six different phases (like the **(a)**–**(f)** in Sect. 7.2) at different times. The mental states of persons are

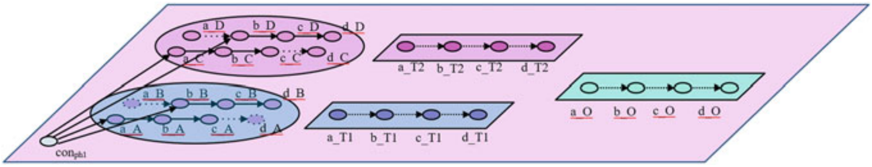

Fig. 7.3 The connectivity of the base level of the adaptive network model: (1) in the ovals the individual mental models of the team members (A and B for Team T1 and C and D for team T2), (2) in the rectangles the shared team mental models for team T1 (blue-grey) and team T2 (pink-purple) and the shared mental model of the whole organisation O (green)

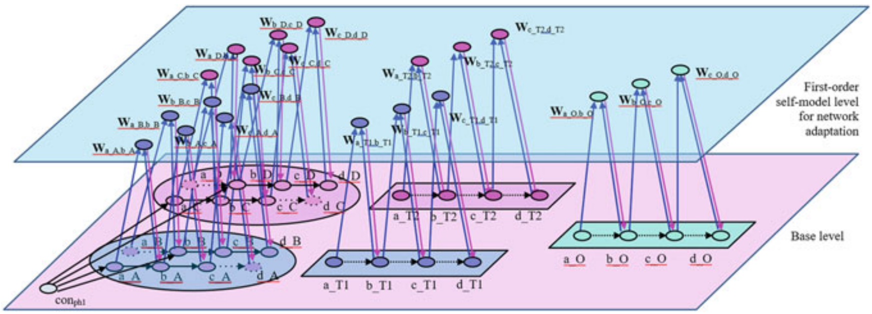

Fig. 7.4 The connectivity between the base level and first-order self-model level for the adaptation of the mental models by Hebbian learning

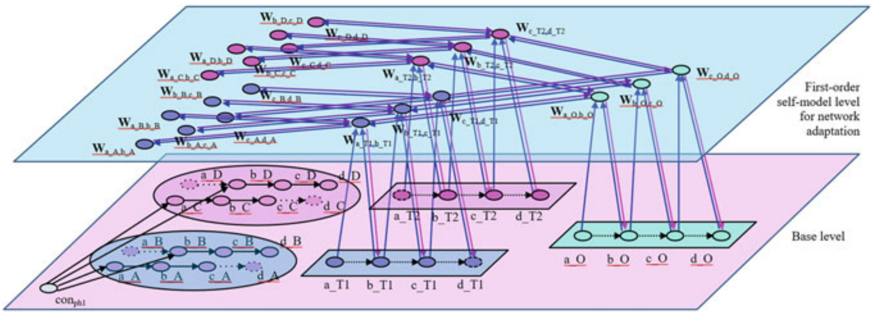

Fig. 7.5 The connectivity within the first-order self-model level for the adaptation of the mental models by formation of shared team and organisation mental models (links from left to right: feed-forward learning) and by instruction learning of individual mental models and shared team mental models from these shared mental models (links from right to left: feedback learning)

connected to each other according to the order of the tasks, and the first ones have a connection from first context state to be able to start to perform internal simulation and learn. As can be seen in Fig. 7.3, some connections between task states of persons are dashed, which means initially there is no connection (initial lack of knowledge).

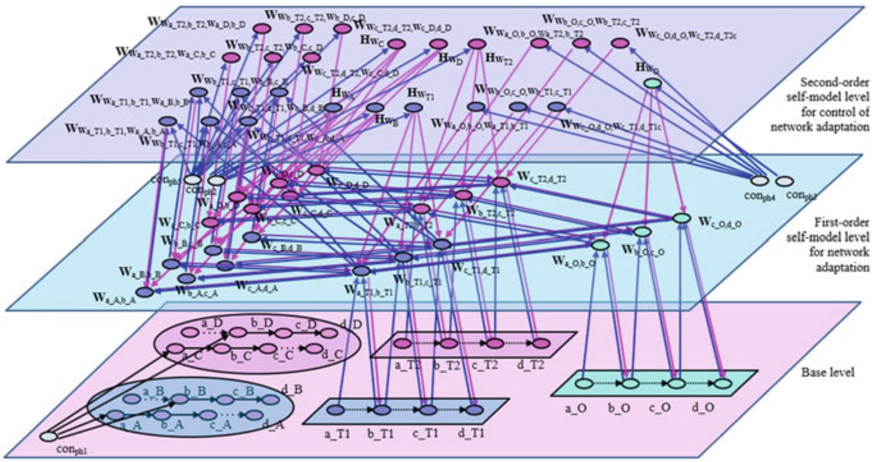

Fig. 7.6 The connectivity of the second-order adaptive network model for the second-order self-model of the mental models: the interactions between the first-order self-model level and the second-order self-model level: the second-order Hebbian learning for the second-order **W**-states (the $\mathbf{W_W}$-states)

Therefore, states where these dashed connections are, are the 'hollow' non-known mental state connections of persons. These states have connections that change over time to enable to observe the improvement of the individual's knowledge with the impact of organisation and team mental models in the fifth phase. The base level mental states relate to the basic tasks and can be considered as the basic ingredients of the mental models representing knowledge on relations between tasks.

To make the mental models adaptive, first-order self-model states are added in the intermediary (first-order self-model) level (blue plane). These are **W**-states representing adaptive weights for each developed connection between individual, team and organisation mental model states in the base level; see Fig. 7.4. The (blue) upward and (pink) downward connections between the two levels are used to model individual (Hebbian) learning.

Within the first-order self-model level (blue plane), there are also intralevel **W**-to-**W** connections between first-order **W**-states here to enable feed forward learning (in Phase 2 and Phase 3) and feedback learning (in Phase 4 and Phase 5) (Crossan et al. 1999). These **W**-to-**W** connections correspond to the arrows for feed forward and feedback learning shown in Fig. 7.1 (upper part, resp. lower part). Thus, formation of shared team and organisation mental models is performed by this feed forward learning mechanism, and the learning from the shared organisation mental model and the shared team mental model by individuals occurs by the feedback learning mechanism.

To control the adaptivity modeled by the first-order adaptation level, second-order self-model states are added in the uppermost level (purple plane). In first place, there

Nr	State	Explanation
X_1	a_A	Individual mental model state for person A for task a
X_2	b_A	Individual mental model state for person A for task b
X_3	c_A	Individual mental model state for person A for task c
X_4	d_A	Individual mental model state for person A for task d
X_5	a_B	Individual mental model state for person B for task a
X_6	b_B	Individual mental model state for person B for task b
X_7	c_B	Individual mental model state for person B for task c
X_8	d_B	Individual mental model state for person B for task d
X_9	a_C	Individual mental model state for person C for task a
X_{10}	b_C	Individual mental model state for person C for task b
X_{11}	c_C	Individual mental model state for person C for task c
X_{12}	d_C	Individual mental model state for person C for task d
X_{13}	a_D	Individual mental model state for person D for task a
X_{14}	b_D	Individual mental model state for person D for task b
X_{15}	c_D	Individual mental model state for person D for task c
X_{16}	d_D	Individual mental model state for person D for task d
X_{17}	a_T1	Shared mental model state for team T1 for task a
X_{18}	b_T1	Shared mental model state for team T1 for task b
X_{19}	c_T1	Shared mental model state for team T1 for task c
X_{20}	d_T1	Shared mental model state for team T1 for task d
X_{21}	a_T2	Shared mental model state for team T2 for task a
X_{22}	b_T2	Shared mental model state for team T2 for task b
X_{23}	c_T2	Shared mental model state for team T2 for task c
X_{24}	d_T2	Shared mental model state for team T2 for task d
X_{25}	a_O	Shared mental model state for organization O for task a
X_{26}	b_O	Shared mental model state for organization O for task b
X_{27}	c_O	Shared mental model state for organization O for task c
X_{28}	d_O	Shared mental model state for organization O for task d
X_{29}	con_{ph1}	Context state for Phase 1: individual mental model simulation and learning
X_{30}	con_{ph2}	Context state for Phase 2: creation of shared mental models for teams T1 and T2
X_{31}	con_{ph3}	Context state for Phase 3: creation of a shared mental model for organization O
X_{32}	con_{ph4}	Context state for Phase 4: learning shared team mental models from the shared mental model for organization O
X_{33}	con_{ph5}	Context state for Phase 5: learning individual mental models from the shared mental models for teams T1 and T2
X_{34}	con_{ph6}	Context state for Phase 6: individual mental model simulation and learning

Fig. 7.7 Base level states of the introduced adaptive network model

are $\mathbf{W_W}$-states (higher-order **W**-states) for (intralevel) connections between first-order adaptivity level **W**-states, in other words adaptive weight representations of the horizontal connections between adaptive weight representation states in the level below. These control processes (for whether and when to activate feed forward and feedback learning) are not explicitly depicted in Fig. 7.1 based on (Wiewiora et al. 2019) and (Crossan et al. 1999) but still are crucial for the processes to function well. Additionally, $\mathbf{H_W}$-states for adaptation speeds of connection weight representations in the first-order adaptation level, and $\mathbf{M_W}$-states for persistence of adaptation are placed on the second-order self-model level. This provides the speed and persistence control of the adaptation.

For a full specification of the network model, see the Appendix section (Sect. 7.7). In Fig. 7.12 an overview is given of the different types of connections.

Nr	State	Explanation
X_{35}	$\mathbf{W}_{a\_A,b\_A}$	First-order self-model state for the weight of the connection from a to b within the individual mental model of person A
X_{36}	$\mathbf{W}_{b\_A,c\_A}$	First-order self-model state for the weight of the connection from b to c within the individual mental model of person A
X_{37}	$\mathbf{W}_{c\_A,d\_A}$	First-order self-model state for the weight of the connection from c to d within the individual mental model of person A
X_{38}	$\mathbf{W}_{a\_B,b\_B}$	First-order self-model state for the weight of the connection from a to b within the individual mental model of person B
X_{39}	$\mathbf{W}_{b\_B,c\_B}$	First-order self-model state for the weight of the connection from b to c within the individual mental model of person B
X_{40}	$\mathbf{W}_{c\_B,d\_B}$	First-order self-model state for the weight of the connection from c to d within the individual mental model of person B
X_{41}	$\mathbf{W}_{a\_C,b\_C}$	First-order self-model state for the weight of the connection from a to b within the individual mental model of person C
X_{42}	$\mathbf{W}_{b\_C,c\_C}$	First-order self-model state for the weight of the connection from b to c within the individual mental model of person C
X_{43}	$\mathbf{W}_{c\_C,d\_C}$	First-order self-model state for the weight of the connection from c to d within the individual mental model of person C
X_{44}	$\mathbf{W}_{a\_D,b\_D}$	First-order self-model state for the weight of the connection from a to b within the individual mental model of person D
X_{45}	$\mathbf{W}_{b\_D,c\_D}$	First-order self-model state for the weight of the connection from b to c within the individual mental model of person D
X_{46}	$\mathbf{W}_{c\_D,d\_D}$	First-order self-model state for the weight of the connection from c to d within the individual mental model of person D
X_{47}	$\mathbf{W}_{a\_T1,b\_T1}$	First-order self-model state for the weight of the connection from a to b within the shared mental model of team T1
X_{48}	$\mathbf{W}_{b\_T1,c\_T1}$	First-order self-model state for the weight of the connection from b to c within the shared mental model of team T1
X_{49}	$\mathbf{W}_{c\_T1,d\_T1}$	First-order self-model state for the weight of the connection from c to d within the shared mental model of team T1
X_{50}	$\mathbf{W}_{a\_T2,b\_T2}$	First-order self-model state for the weight of the connection from a to b within the shared mental model of team T2
X_{51}	$\mathbf{W}_{b\_T2,c\_T2}$	First-order self-model state for the weight of the connection from b to c within the shared mental model of team T2
X_{52}	$\mathbf{W}_{c\_T2,d\_T2}$	First-order self-model state for the weight of the connection from c to d within the shared mental model of team T2
X_{53}	$\mathbf{W}_{a\_O,b\_O}$	First-order self-model state for the weight of the connection from a to b within the shared mental model of the organisation O
X_{54}	$\mathbf{W}_{b\_O,c\_O}$	First-order self-model state for the weight of the connection from b to c within the shared mental model of the organisation O
X_{55}	$\mathbf{W}_{c\_O,d\_O}$	First-order self-model state for the weight of the connection from c to d within the shared mental model of the organisation O

Fig. 7.8 First-order self-model states of the introduced adaptive network model

In summary, first- and second-order self-model states are used to bring multi-order adaptivity to the network model. The first-order adaptation level provides adaptivity of the base level and the second-order one controls this adaptivity. In the first-order self-model level, **W**-states for all the weights of the connections between the base level states are placed. In the first place, these are the adaptive weights of the base level individual mental state connections of persons. In addition, there are **W**-states of the developed shared organisation mental model states. At this first-order adaptation level there are (intralevel) connections from all the **W**-states (two for this case) that specify the weight of a connection between the same tasks for all people (two for this case) to

Nr	State	Explanation
X_{56}	$\mathbf{W}_{W_{a\_T1,b\_T1},W_{a\_A,b\_A}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{a\_T1,b\_T1}$ to individual mental model connection weight self-model state $\mathbf{W}_{a\_A,b\_A}$ for instructional (feedback) learning from the shared mental model of team T1
X_{57}	$\mathbf{W}_{W_{b\_T1,c\_T1},W_{b\_A,c\_A}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{b\_T1,c\_T1}$ to individual mental model connection weight self-model state $\mathbf{W}_{b\_A,c\_A}$ for instructional (feedback) learning from the shared mental model of team T1
X_{58}	$\mathbf{W}_{W_{c\_T1,d\_T1},W_{c\_A,d\_A}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{c\_T1,d\_T1}$ to individual mental model connection weight self-model state $\mathbf{W}_{c\_A,d\_A}$ for instructional (feedback) learning from the shared mental model of team T1
X_{59}	$\mathbf{W}_{W_{a\_T1,b\_T1},W_{a\_B,b\_B}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{a\_T1,b\_T1}$ to individual mental model connection weight self-model state $\mathbf{W}_{a\_B,b\_B}$ for instructional (feedback) learning from the shared mental model of team T1
X_{60}	$\mathbf{W}_{W_{b\_T1,c\_T1},W_{b\_B,c\_B}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{b\_T1,c\_T1}$ to individual mental model connection weight self-model state $\mathbf{W}_{b\_B,c\_B}$ for instructional (feedback) learning from the shared mental model of team T1
X_{61}	$\mathbf{W}_{W_{c\_T1,d\_T1},W_{c\_B,d\_B}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{c\_T1,d\_T1}$ to individual mental model connection weight self-model state $\mathbf{W}_{c\_B,d\_B}$ for instructional (feedback) learning from the shared mental model of team T1
X_{62}	$\mathbf{W}_{W_{a\_T2,b\_T2},W_{a\_C,b\_C}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{a\_T2,b\_T2}$ to individual mental model connection weight self-model state $\mathbf{W}_{a\_C,b\_C}$ for instructional (feedback) learning from the shared mental model of team T2
X_{63}	$\mathbf{W}_{W_{b\_T2,c\_T2},W_{b\_C,c\_C}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{b\_T2,c\_T2}$ to individual mental model connection weight self-model state $\mathbf{W}_{b\_C,c\_C}$ for instructional (feedback) learning of the shared mental model of team T2
X_{64}	$\mathbf{W}_{W_{c\_T2,d\_T2},W_{c\_C,d\_C}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{c\_T2,d\_T2}$ to individual mental model connection weight self-model state $\mathbf{W}_{c\_C,d\_C}$ for instructional (feedback) learning from the shared mental model of team T2
X_{65}	$\mathbf{W}_{W_{a\_T2,b\_T2},W_{a\_D,b\_D}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{a\_T2,b\_T2}$ to individual mental model connection weight self-model state $\mathbf{W}_{a\_D,b\_D}$ for instructional (feedback) learning from the shared mental model of team T2
X_{66}	$\mathbf{W}_{W_{b\_T2,c\_T2},W_{b\_D,c\_D}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{b\_T2,c\_T2}$ to individual mental model connection weight self-model state $\mathbf{W}_{b\_D,c\_D}$ for instructional (feedback) learning from the shared mental model of team T2
X_{67}	$\mathbf{W}_{W_{c\_T2,d\_T2},W_{c\_D,d\_D}}$	Second-order self-model state for the weight of the connection from shared team mental model connection weight self-model state $\mathbf{W}_{c\_T2,d\_T2}$ to individual mental model connection weight self-model state $\mathbf{W}_{c\_D,d\_D}$ for instructional (feedback) learning from the shared mental model of team T2

Fig. 7.9 Second-order self-model states of the introduced adaptive network model: the higher-order **W**-states for feedback learning from shared team mental model to individual mental models

Nr	State	Explanation
X_{68}	$\mathbf{W}_{\mathbf{W}_{a\_O,b\_O},\mathbf{W}_{a\_T1,b\_T1}}$	Second-order self-model state for the weight of the connection from shared organisation mental model connection weight self-model state $\mathbf{W}_{a\_O,b\_O}$ to shared team mental model connection weight self-model state $\mathbf{W}_{a\_T1,b\_T1}$ for instructional (feedback) learning from the shared organisation mental model
X_{69}	$\mathbf{W}_{\mathbf{W}_{b\_O,c\_O},\mathbf{W}_{b\_T1,c\_T1}}$	Second-order self-model state for the weight of the connection from shared organisation mental model connection weight self-model state $\mathbf{W}_{b\_O,c\_O}$ to shared team mental model connection weight self-model state $\mathbf{W}_{b\_T1,c\_T1}$ for instructional (feedback) learning from the shared organisation mental model
X_{70}	$\mathbf{W}_{\mathbf{W}_{c\_O,d\_O},\mathbf{W}_{c\_T1,d\_T1}}$	Second-order self-model state for the weight of the connection from shared organisation mental model connection weight self-model state $\mathbf{W}_{c\_O,d\_O}$ to shared team mental model connection weight self-model state $\mathbf{W}_{c\_T1,d\_T1}$ for instructional (feedback) learning from the shared organisation mental model
X_{71}	$\mathbf{W}_{\mathbf{W}_{a\_O,b\_O},\mathbf{W}_{a\_T2,b\_T2}}$	Second-order self-model state for the weight of the connection from shared organisation mental model connection weight self-model state $\mathbf{W}_{a\_O,b\_O}$ to shared team mental model connection weight self-model state $\mathbf{W}_{a\_T2,b\_T2}$ for instructional (feedback) learning from the shared organisation mental model
X_{72}	$\mathbf{W}_{\mathbf{W}_{b\_O,c\_O},\mathbf{W}_{b\_T2,c\_T2}}$	Second-order self-model state for the weight of the connection from shared organisation mental model connection weight self-model state $\mathbf{W}_{b\_O,c\_O}$ to shared team mental model connection weight self-model state $\mathbf{W}_{b\_T2,c\_T2}$ for instructional (feedback) learning from the shared organisation mental model
X_{73}	$\mathbf{W}_{\mathbf{W}_{c\_O,d\_O},\mathbf{W}_{c\_T2,d\_T2}}$	Second-order self-model state for the weight of the connection from shared organisation mental model connection weight self-model state $\mathbf{W}_{c\_O,d\_O}$ to shared team mental model connection weight self-model state $\mathbf{W}_{c\_T2,d\_T2}$ for instructional (feedback) learning from the shared organisation mental model

Fig. 7.10 Second-order self-model states of the introduced adaptive network model: the higher-order **W**-states for feedback learning from shared organisation mental model to shared team mental models

the **W**-states representing the weights of the connections of the shared organisation model (for the formation of the shared organisation mental model) and vice versa (for the learning of the shared organisation mental model by the individuals). At the second-order self-model level, there are $\mathbf{W}_{\mathbf{W}}$-states specifying the weights of the intralevel connections between the **W**-states to the individual ones (to initiate and control the learning of the shared organisation mental model by the individuals), $\mathbf{H}_{\mathbf{W}}$-states for adaptation speeds of connection weights in the first-order adaptation level, and $\mathbf{M}_{\mathbf{W}}$-states for persistence of adaptation. This provides the speed and persistence control of the adaptation.

7.5 Example Simulation Scenario

In this scenario, for reasons of presentation a multi-phase approach is applied to get a clear picture of the progress of multilevel organisational learning via teams. In general, the model can also process all phases simultaneously. It is possible to see the feed forward flow of the development of shared team mental models from individual mental models first, formation of the shared organisation mental model originating from teams' mental models then, and finally by the feedback flow the impact of these shared mental models on teams and individuals. In practice, and also in the model,

Nr	State	Explanation
X_{74}	$\mathbf{Hw}_{A}$	Second-order self-model state for the adaptation speed of all individual mental model connection weight self-model states $\mathbf{W}_{x\_A,y\_A}$ for formation or revision of the individual mental model of person A
X_{75}	$\mathbf{Hw}_{B}$	Second-order self-model state for the adaptation speed of all individual mental model connection weight self-model states $\mathbf{W}_{x\_B,y\_B}$ for formation or revision of the individual mental model of person B
X_{76}	$\mathbf{Hw}_{C}$	Second-order self-model state for the adaptation speed of all individual mental model connection weight self-model states $\mathbf{W}_{x\_C,y\_C}$ for formation or revision of the individual mental model of person C
X_{77}	$\mathbf{Hw}_{D}$	Second-order self-model state for the adaptation speed of all individual mental model connection weight self-model states $\mathbf{W}_{x\_D,y\_D}$ for formation or revision of the individual mental model of person D
X_{78}	$\mathbf{Hw}_{T1}$	Second-order self-model state for the adaptation speed of shared mental model connection weight self-model state $\mathbf{W}_{x\_T1,y\_T1}$ for formation or revision of the shared mental model of team T1
X_{79}	$\mathbf{Hw}_{T2}$	Second-order self-model state for the adaptation speed of all shared mental model connection weight self-model states $\mathbf{W}_{x\_T2,y\_T2}$ for formation or revision of the shared mental model of team T2
X_{80}	$\mathbf{Hw}_{O}$	Second-order self-model state for the adaptation speed of all shared organisation mental model connection weight self-model states $\mathbf{W}_{x\_O,y\_O}$ for formation or revision of the shared organisation mental model
X_{81}	$\mathbf{Mw}_{a\_A,b\_A}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{a\_A,b\_A}$ of person A
X_{82}	$\mathbf{Mw}_{b\_A,c\_A}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{b\_A,c\_A}$ of person A
X_{83}	$\mathbf{Mw}_{c\_A,d\_A}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{c\_A,d\_A}$ of person A
X_{84}	$\mathbf{Mw}_{a\_B,b\_B}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{a\_B,b\_B}$ of person B
X_{85}	$\mathbf{Mw}_{b\_B,c\_B}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{b\_B,c\_B}$ of person B
X_{86}	$\mathbf{Mw}_{c\_B,d\_B}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{c\_B,d\_B}$ of person B
X_{87}	$\mathbf{Mw}_{a\_C,b\_C}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{a\_C,b\_C}$ of person C
X_{88}	$\mathbf{Mw}_{b\_C,c\_C}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{b\_C,c\_C}$ of person C
X_{89}	$\mathbf{Mw}_{c\_C,d\_C}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{c\_C,d\_C}$ of person C
X_{90}	$\mathbf{Mw}_{a\_D,b\_D}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{a\_D,b\_D}$ of person D
X_{91}	$\mathbf{Mw}_{b\_D,c\_D}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{b\_D,c\_D}$ of person D
X_{92}	$\mathbf{Mw}_{c\_D,d\_D}$	Second-order self-model state for persistence of adaptation of individual mental model connection weight self-model state $\mathbf{W}_{c\_D,d\_D}$ of person D

Fig. 7.11 Second-order self-model states of the introduced adaptive network model: the $\mathbf{H}_{\mathbf{W}}$-states for adaptive learning speed and $\mathbf{M}_{\mathbf{W}}$-states for adaptive persistence of the learning

these phases also can overlap or take place entirely simultaneously. The considered six phases are as follows; see Figs. 7.13, 7.14 and 7.15:

- **Phase 1**: **Individual mental model usage and learning**

This relates to **(a)** in Sect. 7.2. Different individual mental models by four different persons are constructed and strengthened here. The knowledge of people for the tasks, initially, is not same. Thus, the learning levels are different as can be seen in

Intralevel connections		
$x\_Z \to y\_Z$	Connection from x to y in individual mental model of person Z: **(a)** from Sect. 2.3.	
$x\_O \to y\_O$	Connection from x to y in shared mental model of organisation O: **(a)** from Sect. 2.3.	
$\text{con}_p \to x\_Z$	Connection from context state con_p for phase $p \in \{\text{ph1, ph6}\}$ to activate mental model state x of person Z: **(f)** from Sect. 7.2.	
$\mathbf{W}_{x\_Z,y\_Z} \to \mathbf{W}_{x\_T,y\_T}$	Connection for person Z's contribution from the weight of the connection from x to y in the individual mental model of Z to the weight of the connection from x to y in the shared team mental model of team T: **(b)** from Sect. 7.2.	
$\mathbf{W}_{x\_T,y\_T} \to \mathbf{W}_{x\_O,y\_O}$	Connection for team T's contribution from the weight of the connection from x to y in the shared team mental model of Z to the weight of the connection from x to y in the shared organisation mental model of O: **(c)** from Sect. 7.2.	
$\mathbf{W}_{x\_O,y\_O} \to \mathbf{W}_{x\_T,y\_T}$	Connection for O's contribution from the weight of the connection from x to y in the shared organisation mental model of O to the weight of the connection from x to y in the shared team mental model of team T: **(d)** from Sect. 7.2.	
$\mathbf{W}_{x\_T,y\_T} \to \mathbf{W}_{x\_Z,y\_Z}$	Connection for team T's contribution from the weight of the connection from x to y in the shared team mental model of T to the weight of the connection from x to y in the individual mental model of person Z: **(e)** from Sect. 7.2.	
$\mathbf{W}_{x\_Z,y\_Z} \to \mathbf{W}_{x\_Z,y\_Z}$	Persistence connection for Z's mental model connections: **(a)** from Sect. 7.2.	
Interlevel connections		
$x\_Z \to \mathbf{W}_{x\_Z,y\_Z}$	Connection for individual Hebbian learning from state x in person Z's individual mental model to self-model state $\mathbf{W}_{x\_A,y\_A}$ for Z's individual mental model: **(a)** from Sect. 7.2.	Upward from base level to first self-model level
$y\_Z \to \mathbf{W}_{x\_Z,y\_Z}$	Connection for individual Hebbian learning from state y in person Z's individual mental model to self-model state $\mathbf{W}_{x\_A,y\_A}$ for Z's individual mental model: **(a)** from Sect. 7.2.	
$x\_T \to \mathbf{W}_{x\_T,y\_T}$	Connection for individual Hebbian learning from state x in team T's shared mental model to self-model state $\mathbf{W}_{x\_T,y\_T}$ for T's shared mental model: **(b)** from Sect. 7.2.	
$y\_T \to \mathbf{W}_{x\_T,y\_T}$	Connection for individual Hebbian learning from state y in team T's shared mental model to self-model state $\mathbf{W}_{x\_T,y\_T}$ for T's shared mental model: **(b)** from Sect. 7.2.	
$x\_O \to \mathbf{W}_{x\_O,y\_O}$	Connection for Hebbian learning from state x in O's shared mental model to self-model state $\mathbf{W}_{x\_A,y\_A}$ for O's shared mental model: **(c)** from Sect. 7.2.	
$y\_O \to \mathbf{W}_{x\_O,y\_O}$	Connection for Hebbian learning from state y in O's shared mental model to self-model state $\mathbf{W}_{x\_A,y\_A}$ for O's shared mental model: **(c)** from Sect. 7.2.	
$\mathbf{W}_{x\_Z,y\_Z} \to y\_Z$	Connection for the effect of self-model state $\mathbf{W}_{x\_Z,y\_Z}$ for person Z's individual mental model on state y in Z's individual mental model: **(a)** from Sect. 7.2.	Downward from first-order self-model level to base level
$\mathbf{W}_{x\_T,y\_T} \to y\_T$	Connection for the effect of self-model state $\mathbf{W}_{x\_T,y\_T}$ for team T's shared mental model on state y in T's shared mental model: **(b)** from Sect. 7.2.	
$\mathbf{W}_{x\_O,y\_O} \to y\_O$	Connection for the effect of self-model state $\mathbf{W}_{x\_O,y\_O}$ for O's shared mental model on state y in O's shared mental model: **(c)** from Sect. 7.2.	

Fig. 7.12 Types of connections in the adaptive network model and how they relate to **(a)**–**(f)** identified in Sect. 7.2. For the example scenario, x and y are states from {a, b, c, d}, T is a team from {T1, T2} and Z is a person from {A, B, C, D}

the first phase between time 25 and 200 in the simulation graph in Fig. 7.11 (overall) and Fig. 7.12 (the **W**-states). For example, activation levels of first three base states for tasks *a* to *c* of person A from Team 1 and person C from Team 2 (a_A to c_A and a_C to c_C) increase while the activation levels of states for task *d* (d_A and d_C) remain at zero indicating that they do not have knowledge on this task. A similar lack of knowledge is observed for the other persons B from Team 1 and D from Team 2, for task *a* this time. Therefore, the activation levels of their states a_B and a_D remain at zero in this phase, while others get increased (b_B to d_B and

$\mathrm{con}_{ph2} \rightarrow \mathbf{H}\mathrm{w}_{x\_T,y\_T}$	Connection from the context state for Phase 2 to second-order self-model state $\mathbf{H}\mathrm{w}_{a\_T,b\_T}$ representing the adaptation speed of first-order self-model state $\mathbf{W}_{x\_T,y\_T}$ for the weight of the connection from x to y in the shared mental model of team T in order to trigger this adaptation speed for shared mental model formation: **(b)** from Sect. 7.2.	Upward from base level to second-order self-model level
$\mathrm{con}_{ph3} \rightarrow \mathbf{H}\mathrm{w}_{x\_O,y\_O}$	Connection from the context state for Phase 2 to second-order self-model state $\mathbf{H}\mathrm{w}_{a\_O,b\_O}$ representing the adaptation speed of first-order self-model state $\mathbf{W}_{x\_O,y\_O}$ for the weight of the connection from x to y in the shared organisation mental model of O in order to trigger this adaptation speed for shared mental model formation: **(c)** from Sect. 7.2.	
$\mathrm{con}_{ph5} \rightarrow \mathbf{W}\mathrm{w}_{x\_T,y\_T,}\mathrm{w}_{x\_Z,y\_Z}$	Connection from the context state for Phase 3 to second-order self-model state $\mathbf{W}\mathrm{w}_{x\_T,y\_T,}\mathrm{w}_{x\_Z,y\_Z}$ representing the weight of the connection from first-order self-model state $\mathbf{W}_{x\_T,y\_T}$ for the weight of the connection from x to y in the shared mental model of team T to first-order self-model state $\mathbf{W}_{x\_Z,y\_Z}$ for the weight of the connection from x to y in the individual mental model of person Z in order to activate this connection for instructional learning of Z from the shared mental model: **(e)** from Sect. 7.2.	
$\mathrm{con}_{ph4} \rightarrow \mathbf{W}\mathrm{w}_{x\_O,y\_O,}\mathrm{w}_{x\_Z,y\_Z}$	Connection from the context state for Phase 3 to second-order self-model state $\mathbf{W}\mathrm{w}_{x\_O,y\_O,}\mathrm{w}_{x\_Z,y\_Z}$ representing the weight of the connection from first-order self-model state $\mathbf{W}_{x\_O,y\_O}$ for the weight of the connection from x to y in the shared mental model of O to first-order self-model state $\mathbf{W}_{x\_Z,y\_Z}$ for the weight of the connection from x to y in the individual mental model of person Z in order to activate this connection for instructional learning of Z from the shared mental model: **(d)** from Sect. 7.2.	
$\mathbf{H}\mathrm{w}_{x\_O,y\_O} \rightarrow \mathbf{W}_{x\_O,y\_O}$	Effectuation of control of the adaptation of O's shared mental model connection weight $\mathbf{W}_{x\_O,y\_O}$ for shared mental model formation based on Z's individual mental model: **(b)**, **(c)** from Sect. 7.2.	Downward from second- to first-order self-model level
$\mathbf{W}\mathrm{w}_{x\_O,y\_O,}\mathrm{w}_{x\_Z,y\_Z} \rightarrow \mathbf{W}_{x\_Z,y\_Z}$	Effectuation of control of the adaptation of person Z's individual mental model connection weight $\mathbf{W}_{x\_Z,y\_Z}$ for instructional learning of Z's individual mental model from O's shared mental model: **(d)** from Sect. 7.2.	

Fig. 7.12 (continued)

b_D to d_D). After this first individual learning phase, forgetting takes place for all persons because they do not have perfect persistence factors self-model **M**-state values (values <1, meaning imperfection). Increased **W**-states during phase 1, start to slightly decrease after phase 1 at different rates representing the differences between persons concerning forgetting speed.

- **Phase 2: Shared team mental model formation (feed forward learning)**

This relates to **(b)** in Sect. 7.2. Formation of two shared team mental models happens in this phase. The collaboration of the individuals creates the aggregation of their mental models as part of feed forward organisational learning (in this case team learning). The **W**-states of the teams ($\mathbf{W}_{a\_T1,b\_T1}$ to $\mathbf{W}_{c\_T1,d\_T1}$ and $\mathbf{W}_{a\_T2,b\_T2}$ to $\mathbf{W}_{c\_T2,d\_T2}$) increase at different rates in Phase 2 between time 250 and 300 in Figs. 7.11 and 7.12. Team 1 becomes better at the connection $c \rightarrow d$, and Team 2 becomes better at connection $a \rightarrow b$ because the teams have different persons. Then, these shared mental models are maintained by the two teams.

- **Phase 3: Shared organisation mental model formation (feed forward learning)**

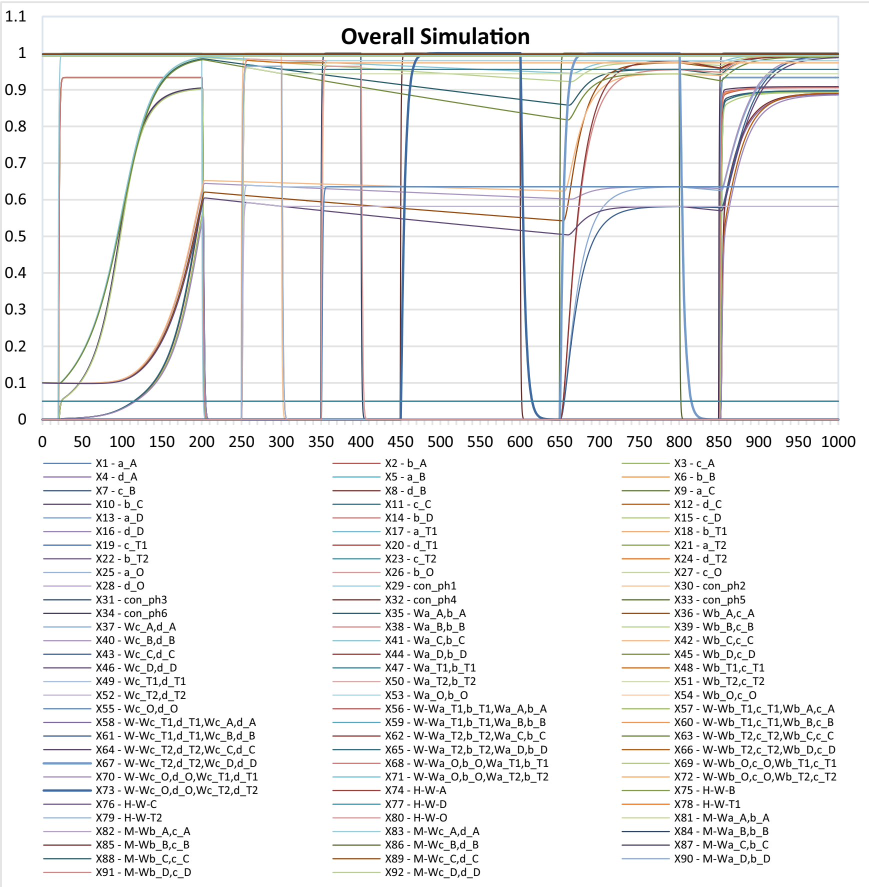

Fig. 7.13 Simulation graph showing all states

This relates to **(c)** in Sect. 7.2. A shared organisation mental model is formed in this phase from the unification and aggregation of the two shared team mental models. The values of shared organisation mental model **W**-states ($\mathbf{W}_{a\_O,b\_O}$ to $\mathbf{W}_{c\_O,d\_O}$) increase here between time 350 and 400.

- **Phase 4: Feedback learning of the shared team mental model from the shared organisation mental model**

This relates to **(d)** in Sect. 7.2. Knowledge from the shared organisation mental model is received by the team mental models as a form of (instructional) feedback learning here in this phase. The (higher-order adaptive) connections from organisation **W**-states to teams **W**-states (X_{68} to X_{73}) become activated, and the teams start to get stronger connections about tasks.

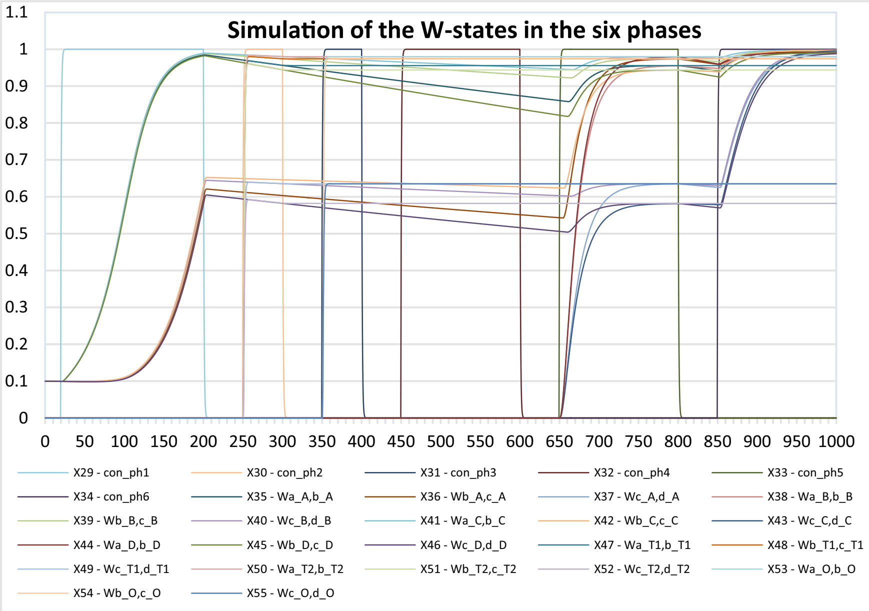

Fig. 7.14 Simulation graph for the **W**-states

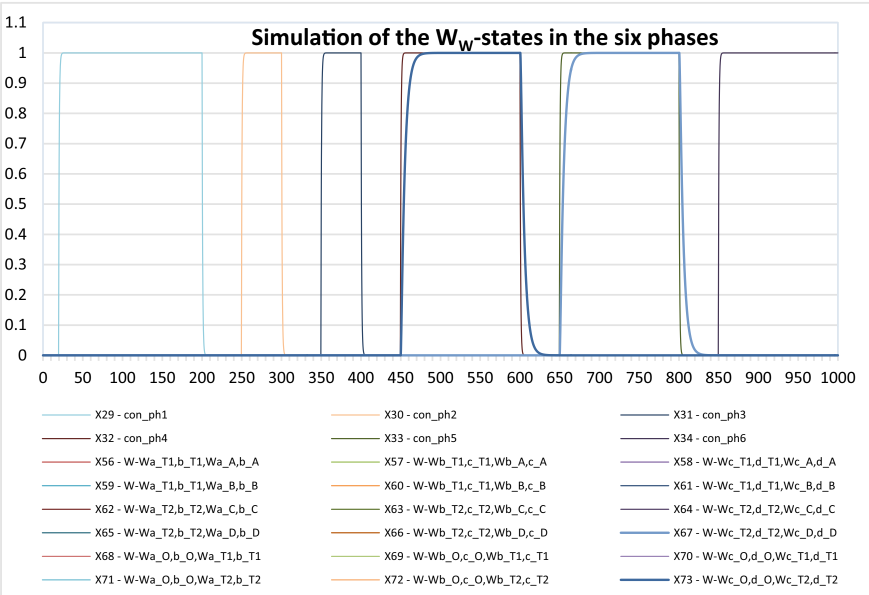

Fig. 7.15 Simulation graph for the $\mathbf{W}_{\mathbf{W}}$-states

- **Phase 5: Feedback learning of the individual mental models from the shared team mental models**

This relates to **(e)** in Sect. 7.2. Improved knowledge from shared team mental models is received by individuals as a form of (instructional) feedback learning in this phase. Higher-order adaptive weight states for connections from teams **W**-states to individual **W**-states (X_{56} to X_{67}) are activated. This provides the learning of individual mental models and gives persons the chance of improving their unknown connections in the next phase. For instance, the person A starts to learn about the task *d* that it does not know in the beginning by the help of its team. In Fig. 7.6, the **W**-states of persons make jumps in this Phase 5 between time 650 and 800.

- **Phase 6: Individual mental model usage and learning**

This relates to **(f)** in Sect. 7.2. Persons start to further improve their knowledge and skills (their mental models) already strengthened in Phase 5 by Hebbian learning (Hebb 1949). Person A's knowledge on task *d* (state d_A) becomes nonzero now (obtained via shared team mental model) and similar improvements are observed for other persons and their 'hollow' unknown states.

7.6 Discussion

The material in this chapter is based on (Canbaloğlu et al. 2023a). Within mainstream organisational learning literature such as (Crossan et al. 1999; Wiewiora et al. 2019), mental models at individual, team and organisation levels and the interplay of them are considered a vehicle for organisational learning. This is called multilevel organisational learning. Based on developed individual mental models, by socalled feed forward learning the formation of shared team mental models can take place and based on them, a shared mental model for the level of the organisation as a whole (see also Fig. 7.1 adopted from the mentioned literature). Once these shared mental models have been formed, they can be adopted by individuals within the organisation, indicated as feedback learning. This involves several mechanisms of different types that by their cyclical interaction together can be considered to form the basis of multilevel organisational learning. These mechanisms have been formalized in a computational manner here and brought together in an adaptive self-modeling network architecture. The model was illustrated by a relatively simple but realistic case study. For the sake of presentation, in the case study scenario the different types of mechanisms have been controlled in such a manner that they are sequentially over time. This is not inherent in the designed computational network model: these processes can equally well work simultaneously. The two lowest levels of the three-level network model describe Fig. 7.1 very well, especially the intralevel connections within the middle level directly correspond to the arrows in Fig. 7.1. However, the necessary control of these processes is left out of consideration in Fig. 7.1 but is fully addressed here by the highest (third) level.

One of the extension possibilities concerns the type of aggregation used for the process of shared mental model formation. In the current model this has been based on the maximal knowledge about a specific mental model connection. But other forms of aggregation can equally well be applied, for example weighted averages. Another possible extension is to make states used for the control adaptive in a context-sensitive manner, such as the second-order self-model **H**- and **M**-states for the individuals, which for the sake of simplicity were kept constant in the current example scenario.

7.7 Appendix: Role Matrices

In Figs. 7.16, 7.17, 7.18, 7.19 and 7.20, the different role matrices are shown that provide a full specification of the network characteristics defining the adaptive network model in a standardised table format. Here in each role matrix, each state has its row where it is listed which are the impacts on it from that role.

Role matrices for **connectivity characteristics**

The connectivity characteristics are specified by role matrices **mb** and **mcw** shown in Figs. 7.16 and 7.17. Role matrix **mb** lists the other states (at the same or lower level) from which the state gets its incoming connections, whereas in role matrix **mcw** the connection weights are listed for these connections.

Nonadaptive connection weights are indicated in **mcw** (in Fig. 7.17) by a number (in a green shaded cell), but adaptive connection weights are indicated by a reference to the (self-model) state representing the adaptive value (in a peach-red shaded cell). This can be seen at the base level for states X_2 to X_4 (with self-model states X_{35} to X_{36}), states X_6 to X_8 (with self-model states X_{38} to X_{40}), X_{10} to X_{12} (with self-model states X_{41} to X_{43}), X_{14} to X_{16} (with self-model states X_{44} to X_{46}), X_{18} to X_{20} (with self-model states X_{47} to X_{49}), X_{22} to X_{24} (with self-model states X_{50} to X_{52}), and X_{26} to X_{28} (with self-model states X_{53} to X_{55}). Similarly, at the first-order self-model level this can be seen for states X_{35} to X_{52} (with self-model states X_{56} to X_{73}). This specifies that all these 39 connections are indeed adaptive with weights represented by states X_{35} to X_{73}.

mb	base connectivity	1	2	3	4	5	6	7	8	9
X_1	a_A	X_{29}	X_{34}							
X_2	b_A	X_1								
X_3	c_A	X_2								
X_4	d_A	X_3								
X_5	a_B	X_{34}								
X_6	b_B	X_5	X_{29}							
X_7	c_B	X_6								
X_8	d_B	X_7								
X_9	a_C	X_{29}	X_{34}							
X_{10}	b_C	X_9								
X_{11}	c_C	X_{10}								
X_{12}	d_C	X_{11}								
X_{13}	a_D	X_{34}								
X_{14}	b_D	X_{13}	X_{29}							
X_{15}	c_D	X_{14}								
X_{16}	d_D	X_{15}								
X_{17}	a_T1									
X_{18}	b_T1	X_{17}								
X_{19}	c_T1	X_{18}								
X_{20}	d_T1	X_{19}								
X_{21}	a_T2									
X_{22}	b_T2	X_{21}								
X_{23}	c_T2	X_{22}								
X_{24}	d_T2	X_{23}								
X_{25}	a_O									
X_{26}	b_O	X_{25}								
X_{27}	c_O	X_{26}								
X_{28}	d_O	X_{27}								
X_{29}	con_{ph1}	X_{29}								
X_{30}	con_{ph2}	X_{30}								
X_{31}	con_{ph3}	X_{31}								
X_{32}	con_{ph4}	X_{32}								
X_{33}	con_{ph5}	X_{33}								
X_{34}	con_{ph6}	X_{34}								

mb	base connectivity	1	2	3	4	5	6	7	8	9
X_{35}	$\mathbf{W}_{a\_A,b\_A}$	X_1	X_2	X_{35}	X_{47}					
X_{36}	$\mathbf{W}_{b\_A,c\_A}$	X_2	X_3	X_{36}	X_{48}					
X_{37}	$\mathbf{W}_{c\_A,d\_A}$	X_3	X_4	X_{37}	X_{49}					
X_{38}	$\mathbf{W}_{a\_B,b\_B}$	X_5	X_6	X_{38}	X_{47}					
X_{39}	$\mathbf{W}_{b\_B,c\_B}$	X_6	X_7	X_{39}	X_{48}					
X_{40}	$\mathbf{W}_{c\_B,d\_B}$	X_7	X_8	X_{40}	X_{49}					
X_{41}	$\mathbf{W}_{a\_C,b\_C}$	X_9	X_{10}	X_{41}	X_{50}					
X_{42}	$\mathbf{W}_{b\_C,c\_C}$	X_{10}	X_{11}	X_{42}	X_{51}					
X_{43}	$\mathbf{W}_{c\_C,d\_C}$	X_{11}	X_{12}	X_{43}	X_{52}					
X_{44}	$\mathbf{W}_{a\_D,b\_D}$	X_{13}	X_{14}	X_{44}	X_{50}					
X_{45}	$\mathbf{W}_{b\_D,c\_D}$	X_{14}	X_{15}	X_{45}	X_{51}					
X_{46}	$\mathbf{W}_{c\_D,d\_D}$	X_{15}	X_{16}	X_{46}	X_{52}					
X_{47}	$\mathbf{W}_{a\_T1,b\_T1}$	X_{17}	X_{18}	X_{35}	X_{38}	X_{47}	X_{53}			
X_{48}	$\mathbf{W}_{b\_T1,c\_T1}$	X_{18}	X_{19}	X_{36}	X_{39}	X_{48}	X_{54}			
X_{49}	$\mathbf{W}_{c\_T1,d\_T1}$	X_{19}	X_{20}	X_{37}	X_{40}	X_{49}	X_{55}			
X_{50}	$\mathbf{W}_{a\_T2,b\_T2}$	X_{21}	X_{22}	X_{41}	X_{44}	X_{50}	X_{53}			
X_{51}	$\mathbf{W}_{b\_T2,c\_T2}$	X_{22}	X_{23}	X_{42}	X_{45}	X_{51}	X_{54}			
X_{52}	$\mathbf{W}_{c\_T2,d\_T2}$	X_{23}	X_{24}	X_{43}	X_{46}	X_{52}	X_{55}			
X_{53}	$\mathbf{W}_{a\_O,b\_O}$	X_{25}	X_{26}	X_{47}	X_{50}	X_{53}				
X_{54}	$\mathbf{W}_{b\_O,c\_O}$	X_{26}	X_{27}	X_{48}	X_{51}	X_{54}				
X_{55}	$\mathbf{W}_{c\_O,d\_O}$	X_{27}	X_{28}	X_{49}	X_{52}	X_{55}				

Fig. 7.16 Role matrices for the connectivity: **mb** for base connectivity

mb	base connectivity	1	2	3	4	5	6	7	8	9
X_{56}	$\mathbf{Ww}_{a\_T1,b\_T1}, \mathbf{w}_{a\_A,b\_A}$	X_{35}	X_{47}	X_{33}						
X_{57}	$\mathbf{Ww}_{b\_T1,c\_T1}, \mathbf{w}_{b\_A,c\_A}$	X_{36}	X_{48}	X_{33}						
X_{58}	$\mathbf{Ww}_{c\_T1,d\_T1}, \mathbf{w}_{c\_A,d\_A}$	X_{37}	X_{49}	X_{33}						
X_{59}	$\mathbf{Ww}_{a\_T1,b\_T1}, \mathbf{w}_{a\_B,b\_B}$	X_{38}	X_{47}	X_{33}						
X_{60}	$\mathbf{Ww}_{b\_T1,c\_T1}, \mathbf{w}_{b\_B,c\_B}$	X_{39}	X_{48}	X_{33}						
X_{61}	$\mathbf{Ww}_{c\_T1,d\_T1}, \mathbf{w}_{c\_B,d\_B}$	X_{40}	X_{49}	X_{33}						
X_{62}	$\mathbf{Ww}_{a\_T2,b\_T2}, \mathbf{w}_{a\_C,b\_C}$	X_{41}	X_{50}	X_{33}						
X_{63}	$\mathbf{Ww}_{b\_T2,c\_T2}, \mathbf{w}_{b\_C,c\_C}$	X_{42}	X_{51}	X_{33}						
X_{64}	$\mathbf{Ww}_{c\_T2,d\_T2}, \mathbf{w}_{c\_C,d\_C}$	X_{43}	X_{52}	X_{33}						
X_{65}	$\mathbf{Ww}_{a\_T2,b\_T2}, \mathbf{w}_{a\_D,b\_D}$	X_{44}	X_{50}	X_{33}						
X_{66}	$\mathbf{Ww}_{b\_T2,c\_T2}, \mathbf{w}_{b\_D,c\_D}$	X_{45}	X_{51}	X_{33}						
X_{67}	$\mathbf{Ww}_{c\_T2,d\_T2}, \mathbf{w}_{c\_D,d\_D}$	X_{46}	X_{52}	X_{33}						
X_{68}	$\mathbf{Ww}_{a\_O,b\_O}, \mathbf{w}_{a\_T1,b\_T1}$	X_{32}								
X_{69}	$\mathbf{Ww}_{b\_O,c\_O}, \mathbf{w}_{b\_T1,c\_T1}$	X_{32}								
X_{70}	$\mathbf{Ww}_{c\_O,d\_O}, \mathbf{w}_{c\_T1,d\_T1}$	X_{32}								
X_{71}	$\mathbf{Ww}_{a\_O,b\_O}, \mathbf{w}_{a\_T2,b\_T2}$	X_{32}								
X_{72}	$\mathbf{Ww}_{b\_O,c\_O}, \mathbf{w}_{b\_T2,c\_T2}$	X_{32}								
X_{73}	$\mathbf{Ww}_{c\_O,d\_O}, \mathbf{w}_{c\_T2,d\_T2}$	X_{32}								
X_{74}	$\mathbf{Hw}_{A}$	X_{30}	X_{1}	X_{2}	X_{3}	X_{4}	X_{35}	X_{36}	X_{37}	X_{74}
X_{75}	$\mathbf{Hw}_{B}$	X_{30}	X_{5}	X_{6}	X_{7}	X_{8}	X_{38}	X_{39}	X_{40}	X_{75}
X_{76}	$\mathbf{Hw}_{C}$	X_{30}	X_{9}	X_{10}	X_{11}	X_{12}	X_{41}	X_{42}	X_{43}	X_{76}
X_{77}	$\mathbf{Hw}_{D}$	X_{30}	X_{13}	X_{14}	X_{15}	X_{16}	X_{44}	X_{45}	X_{46}	X_{77}
X_{78}	$\mathbf{Hw}_{T1}$	X_{30}								
X_{79}	$\mathbf{Hw}_{T2}$	X_{30}								
X_{80}	$\mathbf{Hw}_{O}$	X_{31}								
X_{81}	$\mathbf{Mw}_{a\_A,b\_A}$	X_{1}	X_{2}	X_{35}	X_{81}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{82}	$\mathbf{Mw}_{b\_A,c\_A}$	X_{2}	X_{3}	X_{36}	X_{82}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{83}	$\mathbf{Mw}_{c\_A,d\_A}$	X_{3}	X_{4}	X_{37}	X_{83}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{84}	$\mathbf{Mw}_{a\_B,b\_B}$	X_{5}	X_{6}	X_{38}	X_{84}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{85}	$\mathbf{Mw}_{b\_B,c\_B}$	X_{6}	X_{7}	X_{39}	X_{85}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{86}	$\mathbf{Mw}_{c\_B,d\_B}$	X_{7}	X_{8}	X_{40}	X_{86}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{87}	$\mathbf{Mw}_{a\_C,b\_C}$	X_{8}	X_{9}	X_{41}	X_{87}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{88}	$\mathbf{Mw}_{b\_C,c\_C}$	X_{9}	X_{10}	X_{42}	X_{88}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{89}	$\mathbf{Mw}_{c\_C,d\_C}$	X_{10}	X_{11}	X_{43}	X_{89}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{90}	$\mathbf{Mw}_{a\_D,b\_D}$	X_{11}	X_{12}	X_{44}	X_{90}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{91}	$\mathbf{Mw}_{b\_D,c\_D}$	X_{12}	X_{13}	X_{45}	X_{91}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}
X_{92}	$\mathbf{Mw}_{c\_D,d\_D}$	X_{13}	X_{14}	X_{46}	X_{92}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}

Fig. 7.16 (continued)

Role matrices for **aggregation characteristics**

The network characteristics for aggregation are defined by the selection of combination functions from the library and values for their parameters. In role matrix **mcfw** it is specified by weights which state uses which combination function; see Fig. 7.18.

In role matrix **mcfp** (see Fig. 7.19) it is indicated what the parameter values are for the chosen combination functions. Some of them are adaptive, as can be seen in the rows from X_{35} to X_{46} (the persistence factors $\boldsymbol{\mu}$ represented by the self-model states X_{81} to X_{92}). This specifies that these 12 persistence factors are indeed adaptive with weights represented by states X_{81} to X_{92}.

mcw	connection weights	1	2	3	4	5	6	7	8	9
X_1	a_A	1	1							
X_2	b_A	X_{35}								
X_3	c_A	X_{36}								
X_4	d_A	X_{37}								
X_5	a_B	1								
X_6	b_B	X_{38}	1							
X_7	c_B	X_{39}								
X_8	d_B	X_{40}								
X_9	a_C	1	1							
X_{10}	b_C	X_{41}								
X_{11}	c_C	X_{42}								
X_{12}	d_C	X_{43}								
X_{13}	a_D	1								
X_{14}	b_D	X_{44}	1							
X_{15}	c_D	X_{45}								
X_{16}	d_D	X_{46}								
X_{17}	a_T1									
X_{18}	b_T1	X_{47}								
X_{19}	c_T1	X_{48}								
X_{20}	d_T1	X_{49}								
X_{21}	a_T2									
X_{22}	b_T2	X_{50}								
X_{23}	c_T2	X_{51}								
X_{24}	d_T2	X_{52}								
X_{25}	a_O									
X_{26}	b_O	X_{53}								
X_{27}	c_O	X_{54}								
X_{28}	d_O	X_{55}								
X_{29}	con_{ph1}	1								
X_{30}	con_{ph2}	1								
X_{31}	con_{ph3}	1								
X_{32}	con_{ph4}	1								
X_{33}	con_{ph5}	1								
X_{34}	con_{ph6}	1								

mcw	connection weights	1	2	3	4	5	6	7	8	9
X_{35}	$\mathbf{W}_{a\_A,b\_A}$	1	1	1	X_{56}					
X_{36}	$\mathbf{W}_{b\_A,c\_A}$	1	1	1	X_{57}					
X_{37}	$\mathbf{W}_{c\_A,d\_A}$	1	1	1	X_{58}					
X_{38}	$\mathbf{W}_{a\_B,b\_B}$	1	1	1	X_{59}					
X_{39}	$\mathbf{W}_{b\_B,c\_B}$	1	1	1	X_{60}					
X_{40}	$\mathbf{W}_{c\_B,d\_B}$	1	1	1	X_{61}					
X_{41}	$\mathbf{W}_{a\_C,b\_C}$	1	1	1	X_{62}					
X_{42}	$\mathbf{W}_{b\_C,c\_C}$	1	1	1	X_{63}					
X_{43}	$\mathbf{W}_{c\_C,d\_C}$	1	1	1	X_{64}					
X_{44}	$\mathbf{W}_{a\_D,b\_D}$	1	1	1	X_{65}					
X_{45}	$\mathbf{W}_{b\_D,c\_D}$	1	1	1	X_{66}					
X_{46}	$\mathbf{W}_{c\_D,d\_D}$	1	1	1	X_{67}					
X_{47}	$\mathbf{W}_{a\_T1,b\_T1}$	1	1	X_{68}	1					
X_{48}	$\mathbf{W}_{b\_T1,c\_T1}$	1	1	X_{69}	1					
X_{49}	$\mathbf{W}_{c\_T1,d\_T1}$	1	1	X_{70}	1					
X_{50}	$\mathbf{W}_{a\_T2,b\_T2}$	1	1	X_{71}	1					
X_{51}	$\mathbf{W}_{b\_T2,c\_T2}$	1	1	X_{72}	1					
X_{52}	$\mathbf{W}_{c\_T2,d\_T2}$	1	1	X_{73}	1					
X_{53}	$\mathbf{W}_{a\_O,b\_O}$	1	1	1	1					
X_{54}	$\mathbf{W}_{b\_O,c\_O}$	1	1	1	1					
X_{55}	$\mathbf{W}_{c\_O,d\_O}$	1	1	1	1					

Fig. 7.17 Role matrices for the connectivity: **mcw** for connection weights

mcw	connection weights	1	2	3	4	5	6	7	8	9
X_{56}	$\mathbf{W}w_{a\_T1,b\_T1,}w_{a\_A,b\_A}$	1	1	1						
X_{57}	$\mathbf{W}w_{b\_T1,c\_T1,}w_{b\_A,c\_A}$	1	1	1						
X_{58}	$\mathbf{W}w_{c\_T1,d\_T1,}w_{c\_A,d\_A}$	1	1	1						
X_{59}	$\mathbf{W}w_{a\_T1,b\_T1,}w_{a\_B,b\_B}$	1	1	1						
X_{60}	$\mathbf{W}w_{b\_T1,c\_T1,}w_{b\_B,c\_B}$	1	1	1						
X_{61}	$\mathbf{W}w_{c\_T1,d\_T1,}w_{c\_B,d\_B}$	1	1	1						
X_{62}	$\mathbf{W}w_{a\_T2,b\_T2,}w_{a\_C,b\_C}$	1	1	1						
X_{63}	$\mathbf{W}w_{b\_T2,c\_T2,}w_{b\_C,c\_C}$	1	1	1						
X_{64}	$\mathbf{W}w_{c\_T2,d\_T2,}w_{c\_C,d\_C}$	1	1	1						
X_{65}	$\mathbf{W}w_{a\_T2,b\_T2,}w_{a\_D,b\_D}$	1	1	1						
X_{66}	$\mathbf{W}w_{b\_T2,c\_T2,}w_{b\_D,c\_D}$	1	1	1						
X_{67}	$\mathbf{W}w_{c\_T2,d\_T2,}w_{c\_D,d\_D}$	1	1	1						
X_{68}	$\mathbf{W}w_{a\_O,b\_O,}w_{a\_T1,b\_T1}$	1								
X_{69}	$\mathbf{W}w_{b\_O,c\_O,}w_{b\_T1,c\_T1}$	1								
X_{70}	$\mathbf{W}w_{c\_O,d\_O,}w_{c\_T1,d\_T1}$	1								
X_{71}	$\mathbf{W}w_{a\_O,b\_O,}w_{a\_T2,b\_T2}$	1								
X_{72}	$\mathbf{W}w_{b\_O,c\_O,}w_{b\_T2,c\_T2}$	1								
X_{73}	$\mathbf{W}w_{c\_O,d\_O,}w_{c\_T2,d\_T2}$	1								
X_{74}	$\mathbf{H}w_A$	1	1	1	1	1	-0.1	-0.1	-0.1	1
X_{75}	$\mathbf{H}w_B$	1	1	1	1	1	-0.1	-0.1	-0.1	1
X_{76}	$\mathbf{H}w_C$	1	1	1	1	1	-0.1	-0.1	-0.1	1
X_{77}	$\mathbf{H}w_D$	1	1	1	1	1	-0.1	-0.1	-0.1	1
X_{78}	$\mathbf{H}w_{T1}$	1								
X_{79}	$\mathbf{H}w_{T2}$	1								
X_{80}	$\mathbf{H}w_O$	1								
X_{81}	$\mathbf{M}w_{a\_A,b\_A}$	1	1	1	1	-1	-1	-1	-1	-1
X_{82}	$\mathbf{M}w_{b\_A,c\_A}$	1	1	1	1	-1	-1	-1	-1	-1
X_{83}	$\mathbf{M}w_{c\_A,d\_A}$	1	1	1	1	-1	-1	-1	-1	-1
X_{84}	$\mathbf{M}w_{a\_B,b\_B}$	1	1	1	1	-1	-1	-1	-1	-1
X_{85}	$\mathbf{M}w_{b\_B,c\_B}$	1	1	1	1	-1	-1	-1	-1	-1
X_{86}	$\mathbf{M}w_{c\_B,d\_B}$	1	1	1	1	-1	-1	-1	-1	-1
X_{87}	$\mathbf{M}w_{a\_C,b\_C}$	1	1	1	1	-1	-1	-1	-1	-1
X_{88}	$\mathbf{M}w_{b\_C,c\_C}$	1	1	1	1	-1	-1	-1	-1	-1
X_{89}	$\mathbf{M}w_{c\_C,d\_C}$	1	1	1	1	-1	-1	-1	-1	-1
X_{90}	$\mathbf{M}w_{a\_D,b\_D}$	1	1	1	1	-1	-1	-1	-1	-1
X_{91}	$\mathbf{M}w_{b\_D,c\_D}$	1	1	1	1	-1	-1	-1	-1	-1
X_{92}	$\mathbf{M}w_{c\_D,d\_D}$	1	1	1	1	-1	-1	-1	-1	-1

Fig. 7.17 (continued)

Role matrices for **timing characteristics**

In Fig. 7.20, the role matrix **ms** for speed factors is shown, which lists all speed factors. Next to it, the list of initial values can be found. Also, for **ms** some entries are adaptive: the speed factors of X_{35} to X_{55} are represented by (second-order) self-model states X_{74} to X_{80}. This specifies that all these 21 speed factors are indeed adaptive with weights represented by states X_{74} to X_{80}.

mcfw	combination function weights	1 alogistic	2 steponce	3 maxhebb	4 smax
X_1	a_A	1			
X_2	b_A	1			
X_3	c_A	1			
X_4	d_A	1			
X_5	a_B	1			
X_6	b_B	1			
X_7	c_B	1			
X_8	d_B	1			
X_9	a_C	1			
X_{10}	b_C	1			
X_{11}	c_C	1			
X_{12}	d_C	1			
X_{13}	a_D	1			
X_{14}	b_D	1			
X_{15}	c_D	1			
X_{16}	d_D	1			
X_{17}	a_T1	1			
X_{18}	b_T1	1			
X_{19}	c_T1	1			
X_{20}	d_T1	1			
X_{21}	a_T2	1			
X_{22}	b_T2	1			
X_{23}	c_T2	1			
X_{24}	d_T2	1			
X_{25}	a_O	1			
X_{26}	b_O	1			
X_{27}	c_O	1			
X_{28}	d_O	1			
X_{29}	con_{ph1}		1		
X_{30}	con_{ph2}		1		
X_{31}	con_{ph3}		1		
X_{32}	con_{ph4}		1		
X_{33}	con_{ph5}		1		
X_{34}	con_{ph6}		1		

mcfw	combination function weights	1 alogistic	2 steponce	3 maxhebb	4 smax
X_{35}	$\mathbf{W}_{a\_A,b\_A}$			1	
X_{36}	$\mathbf{W}_{b\_A,c\_A}$			1	
X_{37}	$\mathbf{W}_{c\_A,d\_A}$			1	
X_{38}	$\mathbf{W}_{a\_B,b\_B}$			1	
X_{39}	$\mathbf{W}_{b\_B,c\_B}$			1	
X_{40}	$\mathbf{W}_{c\_B,d\_B}$			1	
X_{41}	$\mathbf{W}_{a\_C,b\_C}$			1	
X_{42}	$\mathbf{W}_{b\_C,c\_C}$			1	
X_{43}	$\mathbf{W}_{c\_C,d\_C}$			1	
X_{44}	$\mathbf{W}_{a\_D,b\_D}$			1	
X_{45}	$\mathbf{W}_{b\_D,c\_D}$			1	
X_{46}	$\mathbf{W}_{c\_D,d\_D}$			1	
X_{47}	$\mathbf{W}_{a\_T1,b\_T1}$				1
X_{48}	$\mathbf{W}_{b\_T1,c\_T1}$				1
X_{49}	$\mathbf{W}_{c\_T1,d\_T1}$				1
X_{50}	$\mathbf{W}_{a\_T2,b\_T2}$				1
X_{51}	$\mathbf{W}_{b\_T2,c\_T2}$				1
X_{52}	$\mathbf{W}_{c\_T2,d\_T2}$				1
X_{53}	$\mathbf{W}_{a\_O,b\_O}$				1
X_{54}	$\mathbf{W}_{b\_O,c\_O}$				1
X_{55}	$\mathbf{W}_{c\_O,d\_O}$				1

Fig. 7.18 Role matrices for the aggregation characteristics: **mcfw** for combination function weights

mcfw	combination function weights	1 alogistic	2 steponce	3 maxhebb	4 smax
X_{56}	$\mathbf{W}w_{a\_T1,b\_T1},w_{a\_A,b\_A}$				1
X_{57}	$\mathbf{W}w_{b\_T1,c\_T1},w_{b\_A,c\_A}$				1
X_{58}	$\mathbf{W}w_{c\_T1,d\_T1},w_{c\_A,d\_A}$				1
X_{59}	$\mathbf{W}w_{a\_T1,b\_T1},w_{a\_B,b\_B}$				1
X_{60}	$\mathbf{W}w_{b\_T1,c\_T1},w_{b\_B,c\_B}$				1
X_{61}	$\mathbf{W}w_{c\_T1,d\_T1},w_{c\_B,d\_B}$				1
X_{62}	$\mathbf{W}w_{a\_T2,b\_T2},w_{a\_C,b\_C}$				1
X_{63}	$\mathbf{W}w_{b\_T2,c\_T2},w_{b\_C,c\_C}$				1
X_{64}	$\mathbf{W}w_{c\_T2,d\_T2},w_{c\_C,d\_C}$				1
X_{65}	$\mathbf{W}w_{a\_T2,b\_T2},w_{a\_D,b\_D}$				1
X_{66}	$\mathbf{W}w_{b\_T2,c\_T2},w_{b\_D,c\_D}$				1
X_{67}	$\mathbf{W}w_{c\_T2,d\_T2},w_{c\_D,d\_D}$				1
X_{68}	$\mathbf{W}w_{a\_O,b\_O},w_{a\_T1,b\_T1}$				1
X_{69}	$\mathbf{W}w_{b\_O,c\_O},w_{b\_T1,c\_T1}$				1
X_{70}	$\mathbf{W}w_{c\_O,d\_O},w_{c\_T1,d\_T1}$				1
X_{71}	$\mathbf{W}w_{a\_O,b\_O},w_{a\_T2,b\_T2}$				1
X_{72}	$\mathbf{W}w_{b\_O,c\_O},w_{b\_T2,c\_T2}$				1
X_{73}	$\mathbf{W}w_{c\_O,d\_O},w_{c\_T2,d\_T2}$				1
X_{74}	$\mathbf{H}w_{A}$	1			
X_{75}	$\mathbf{H}w_{B}$	1			
X_{76}	$\mathbf{H}w_{C}$	1			
X_{77}	$\mathbf{H}w_{D}$	1			
X_{78}	$\mathbf{H}w_{T1}$	1			
X_{79}	$\mathbf{H}w_{T2}$	1			
X_{80}	$\mathbf{H}w_{O}$	1			
X_{81}	$\mathbf{M}w_{a\_A,b\_A}$	1			
X_{82}	$\mathbf{M}w_{b\_A,c\_A}$	1			
X_{83}	$\mathbf{M}w_{c\_A,d\_A}$	1			
X_{84}	$\mathbf{M}w_{a\_B,b\_B}$	1			
X_{85}	$\mathbf{M}w_{b\_B,c\_B}$	1			
X_{86}	$\mathbf{M}w_{c\_B,d\_B}$	1			
X_{87}	$\mathbf{M}w_{a\_C,b\_C}$	1			
X_{88}	$\mathbf{M}w_{b\_C,c\_C}$	1			
X_{89}	$\mathbf{M}w_{c\_C,d\_C}$	1			
X_{90}	$\mathbf{M}w_{a\_D,b\_D}$	1			
X_{91}	$\mathbf{M}w_{b\_D,c\_D}$	1			
X_{92}	$\mathbf{M}w_{c\_D,d\_D}$	1			

Fig. 7.18 (continued)

mcfp	combination function parameters	1 alogistic		2 steponce		3 maxhebb		4 smax	
		1	2	1	2	1	2	1	2
		σ	τ	α	β	μ		λ	
X_1	a_A	5	0.3						
X_2	b_A	5	0.3						
X_3	c_A	5	0.3						
X_4	d_A	5	0.3						
X_5	a_B	5	0.3						
X_6	b_B	5	0.3						
X_7	c_B	5	0.3						
X_8	d_B	5	0.3						
X_9	a_C	5	0.3						
X_{10}	b_C	5	0.3						
X_{11}	c_C	5	0.3						
X_{12}	d_C	5	0.3						
X_{13}	a_D	5	0.3						
X_{14}	b_D	5	0.3						
X_{15}	c_D	5	0.3						
X_{16}	d_D	5	0.3						
X_{17}	a_T1	5	0.3						
X_{18}	b_T1	5	0.3						
X_{19}	c_T1	5	0.3						
X_{20}	d_T1	5	0.3						
X_{21}	a_T2	5	0.3						
X_{22}	b_T2	5	0.3						
X_{23}	c_T2	5	0.3						
X_{24}	d_T2	5	0.3						
X_{25}	a_O	5	0.3						
X_{26}	b_O	5	0.3						
X_{27}	c_O	5	0.3						
X_{28}	d_O	5	0.3						
X_{29}	con_{ph1}			20	200				
X_{30}	con_{ph2}			250	300				
X_{31}	con_{ph3}			350	400				
X_{32}	con_{ph4}			450	600				
X_{33}	con_{ph5}			650	800				
X_{34}	con_{ph6}			850	1000				

mcfp	combination function parameters	1 alogistic		2 steponce		3 maxhebb		4 smax	
		1	2	1	2	1	2	1	2
		σ	τ	α	β	μ		λ	
X_{35}	$\mathbf{W}_{a\ A,b\ A}$					X_{81}			
X_{36}	$\mathbf{W}_{b\ A,c\ A}$					X_{82}			
X_{37}	$\mathbf{W}_{c\ A,d\ A}$					X_{83}			
X_{38}	$\mathbf{W}_{a\ B,b\ B}$					X_{84}			
X_{39}	$\mathbf{W}_{b\ B,c\ B}$					X_{85}			
X_{40}	$\mathbf{W}_{c\ B,d\_B}$					X_{86}			
X_{41}	$\mathbf{W}_{a\ C,b\ C}$					X_{87}			
X_{42}	$\mathbf{W}_{b\ C,c\ C}$					X_{88}			
X_{43}	$\mathbf{W}_{c\ C,d\ C}$					X_{89}			
X_{44}	$\mathbf{W}_{a\ D,b\ D}$					X_{90}			
X_{45}	$\mathbf{W}_{b\ D,c\ D}$					X_{91}			
X_{46}	$\mathbf{W}_{c\_D,d\_D}$					X_{92}			
X_{47}	$\mathbf{W}_{a\ T1,b\ T1}$							1	
X_{48}	$\mathbf{W}_{b\ T1,c\ T1}$							1	
X_{49}	$\mathbf{W}_{c\ T1,d\ T1}$							1	
X_{50}	$\mathbf{W}_{a\ T2,b\ T2}$							1	
X_{51}	$\mathbf{W}_{b\ T2,c\ T2}$							1	
X_{52}	$\mathbf{W}_{c\ T2,d\_T2}$							1	

Fig. 7.19 Role matrices for the aggregation characteristics: **mcfp** for combination function parameters

mcfp	combination function parameters	1 alogistic		2 steponce		3 maxhebb		4 smax	
		1 σ	2 τ	1 α	2 β	1 μ	2	1 λ	2
X_{56}	$\mathbf{W}w_{a\_T1,b\_T1},w_{a\_A,b\_A}$							1	
X_{57}	$\mathbf{W}w_{b\_T1,c\_T1},w_{b\_A,c\_A}$							1	
X_{58}	$\mathbf{W}w_{c\_T1,d\_T1},w_{c\_A,d\_A}$							1	
X_{59}	$\mathbf{W}w_{a\_T1,b\_T1},w_{a\_B,b\_B}$							1	
X_{60}	$\mathbf{W}w_{b\_T1,c\_T1},w_{b\_B,c\_B}$							1	
X_{61}	$\mathbf{W}w_{c\_T1,d\_T1},w_{c\_B,d\_B}$							1	
X_{62}	$\mathbf{W}w_{a\_T2,b\_T2},w_{a\_C,b\_C}$							1	
X_{63}	$\mathbf{W}w_{b\_T2,c\_T2},w_{b\_C,c\_C}$							1	
X_{64}	$\mathbf{W}w_{c\_T2,d\_T2},w_{c\_C,d\_C}$							1	
X_{65}	$\mathbf{W}w_{a\_T2,b\_T2},w_{a\_D,b\_D}$							1	
X_{66}	$\mathbf{W}w_{b\_T2,c\_T2},w_{b\_D,c\_D}$							1	
X_{67}	$\mathbf{W}w_{c\_T2,d\_T2},w_{c\_D,d\_D}$							1	
X_{68}	$\mathbf{W}w_{a\_O,b\_O},w_{a\_T1,b\_T1}$							1	
X_{69}	$\mathbf{W}w_{b\_O,c\_O},w_{b\_T1,c\_T1}$							1	
X_{70}	$\mathbf{W}w_{c\_O,d\_O},w_{c\_T1,d\_T1}$							1	
X_{71}	$\mathbf{W}w_{a\_O,b\_O},w_{a\_T2,b\_T2}$							1	
X_{72}	$\mathbf{W}w_{b\_O,c\_O},w_{b\_T2,c\_T2}$							1	
X_{73}	$\mathbf{W}w_{c\_O,d\_O},w_{c\_T2,d\_T2}$							1	
X_{74}	$\mathbf{H}w_{A}$	5	0.3						
X_{75}	$\mathbf{H}w_{B}$	5	0.3						
X_{76}	$\mathbf{H}w_{C}$	5	0.3						
X_{77}	$\mathbf{H}w_{D}$	5	0.3						
X_{78}	$\mathbf{H}w_{T1}$	5	0.3						
X_{79}	$\mathbf{H}w_{T2}$	5	0.3						
X_{80}	$\mathbf{H}w_{O}$	5	0.3						
X_{81}	$\mathbf{M}w_{a\_A,b\_A}$	5	2						
X_{82}	$\mathbf{M}w_{b\_A,c\_A}$	5	2						
X_{83}	$\mathbf{M}w_{c\_A,d\_A}$	5	2						
X_{84}	$\mathbf{M}w_{a\_B,b\_B}$	5	2						
X_{85}	$\mathbf{M}w_{b\_B,c\_B}$	5	2						
X_{86}	$\mathbf{M}w_{c\_B,d\_B}$	5	2						
X_{87}	$\mathbf{M}w_{a\_C,b\_C}$	5	2						
X_{88}	$\mathbf{M}w_{b\_C,c\_C}$	5	2						
X_{89}	$\mathbf{M}w_{c\_C,d\_C}$	5	2						
X_{90}	$\mathbf{M}w_{a\_D,b\_D}$	5	2						
X_{91}	$\mathbf{M}w_{b\_D,c\_D}$	5	2						
X_{92}	$\mathbf{M}w_{c\_D,d\_D}$	5	2						

Fig. 7.19 (continued)

ms	**speed factors**	1	**initial values**	1
X_1	a_A	1		0
X_2	b_A	1		0
X_3	c_A	1		0
X_4	d_A	1		0
X_5	a_B	1		0
X_6	b_B	1		0
X_7	c_B	1		0
X_8	d_B	1		0
X_9	a_C	1		0
X_{10}	b_C	1		0
X_{11}	c_C	1		0
X_{12}	d_C	1		0
X_{13}	a_D	1		0
X_{14}	b_D	1		0
X_{15}	c_D	1		0
X_{16}	d_D	1		0
X_{17}	a_T1	1		0
X_{18}	b_T1	1		0
X_{19}	c_T1	1		0
X_{20}	d_T1	1		0
X_{21}	a_T2	1		0
X_{22}	b_T2	1		0
X_{23}	c_T2	1		0
X_{24}	d_T2	1		0
X_{25}	a_O	1		0
X_{26}	b_O	1		0
X_{27}	c_O	1		0
X_{28}	d_O	1		0
X_{29}	con_{ph1}	1		0
X_{30}	con_{ph2}	1		0
X_{31}	con_{ph3}	1		0
X_{32}	con_{ph4}	1		0
X_{33}	con_{ph5}	1		0
X_{34}	con_{ph6}	1		0

ms	**speed factors**	1	**initial values**	1
X_{35}	$\mathbf{W}_{a\_A,b\_A}$	X_{74}		0.1
X_{36}	$\mathbf{W}_{b\_A,c\_A}$	X_{74}		0.1
X_{37}	$\mathbf{W}_{c\_A,d\_A}$	X_{74}		0
X_{38}	$\mathbf{W}_{a\_B,b\_B}$	X_{75}		0
X_{39}	$\mathbf{W}_{b\_B,c\_B}$	X_{75}		0.1
X_{40}	$\mathbf{W}_{c\_B,d\_B}$	X_{75}		0.1
X_{41}	$\mathbf{W}_{a\_C,b\_C}$	X_{76}		0.1
X_{42}	$\mathbf{W}_{b\_C,c\_C}$	X_{76}		0.1
X_{43}	$\mathbf{W}_{c\_C,d\_C}$	X_{76}		0
X_{44}	$\mathbf{W}_{a\_D,b\_D}$	X_{77}		0
X_{45}	$\mathbf{W}_{b\_D,c\_D}$	X_{77}		0.1
X_{46}	$\mathbf{W}_{c\_D,d\_D}$	X_{77}		0.1
X_{47}	$\mathbf{W}_{a\_T1,b\_T1}$	X_{78}		0
X_{48}	$\mathbf{W}_{b\_T1,c\_T1}$	X_{78}		0
X_{49}	$\mathbf{W}_{c\_T1,d\_T1}$	X_{78}		0
X_{50}	$\mathbf{W}_{a\_T2,b\_T2}$	X_{79}		0
X_{51}	$\mathbf{W}_{b\_T2,c\_T2}$	X_{79}		0
X_{52}	$\mathbf{W}_{c\_T2,d\_T2}$	X_{79}		0
X_{53}	$\mathbf{W}_{a\_O,b\_O}$	X_{80}		0
X_{54}	$\mathbf{W}_{b\_O,c\_O}$	X_{80}		0
X_{55}	$\mathbf{W}_{c\_O,d\_O}$	X_{80}		0

Fig. 7.20 Role matrix **ms** for the timing characteristics (speed factors) and initial values **iv**

ms	speed factors	1	initial values	1
X_{56}	$\mathbf{W}w_{a\_T1,b\_T1},w_{a\_A,b\_A}$	0.2		0.1
X_{57}	$\mathbf{W}w_{b\_T1,c\_T1},w_{b\_A,c\_A}$	0.2		0.1
X_{58}	$\mathbf{W}w_{c\_T1,d\_T1},w_{c\_A,d\_A}$	0.2		0.1
X_{59}	$\mathbf{W}w_{a\_T1,b\_T1},w_{a\_B,b\_B}$	0.2		0.1
X_{60}	$\mathbf{W}w_{b\_T1,c\_T1},w_{b\_B,c\_B}$	0.2		0.1
X_{61}	$\mathbf{W}w_{c\_T1,d\_T1},w_{c\_B,d\_B}$	0.2		0.1
X_{62}	$\mathbf{W}w_{a\_T2,b\_T2},w_{a\_C,b\_C}$	0.2		0.1
X_{63}	$\mathbf{W}w_{b\_T2,c\_T2},w_{b\_C,c\_C}$	0.2		0.1
X_{64}	$\mathbf{W}w_{c\_T2,d\_T2},w_{c\_C,d\_C}$	0.2		0.1
X_{65}	$\mathbf{W}w_{a\_T2,b\_T2},w_{a\_D,b\_D}$	0.2		0.1
X_{66}	$\mathbf{W}w_{b\_T2,c\_T2},w_{b\_D,c\_D}$	0.2		0.1
X_{67}	$\mathbf{W}w_{c\_T2,d\_T2},w_{c\_D,d\_D}$	0.2		0.1
X_{68}	$\mathbf{W}w_{a\_O,b\_O},w_{a\_T1,b\_T1}$	0.2		0.1
X_{69}	$\mathbf{W}w_{b\_O,c\_O},w_{b\_T1,c\_T1}$	0.2		0.1
X_{70}	$\mathbf{W}w_{c\_O,d\_O},w_{c\_T1,d\_T1}$	0.2		0.1
X_{71}	$\mathbf{W}w_{a\_O,b\_O},w_{a\_T2,b\_T2}$	0.2		0.1
X_{72}	$\mathbf{W}w_{b\_O,c\_O},w_{b\_T2,c\_T2}$	0.2		0.1
X_{73}	$\mathbf{W}w_{c\_O,d\_O},w_{c\_T2,d\_T2}$	0.2		0.1
X_{74}	$\mathbf{H}w_{A}$	0		0.05
X_{75}	$\mathbf{H}w_{B}$	0		0.05
X_{76}	$\mathbf{H}w_{C}$	0		0.05
X_{77}	$\mathbf{H}w_{D}$	0		0.05
X_{78}	$\mathbf{H}w_{T1}$	0.9		0
X_{79}	$\mathbf{H}w_{T2}$	0.9		0
X_{80}	$\mathbf{H}w_{O}$	0.9		0
X_{81}	$\mathbf{M}w_{a\_A,b\_A}$	0		0.994
X_{82}	$\mathbf{M}w_{b\_A,c\_A}$	0		0.994
X_{83}	$\mathbf{M}w_{c\_A,d\_A}$	0		0.994
X_{84}	$\mathbf{M}w_{a\_B,b\_B}$	0		0.997
X_{85}	$\mathbf{M}w_{b\_B,c\_B}$	0		0.997
X_{86}	$\mathbf{M}w_{c\_B,d\_B}$	0		0.997
X_{87}	$\mathbf{M}w_{a\_C,b\_C}$	0		0.998
X_{88}	$\mathbf{M}w_{b\_C,c\_C}$	0		0.998
X_{89}	$\mathbf{M}w_{c\_C,d\_C}$	0		0.998
X_{90}	$\mathbf{M}w_{a\_D,b\_D}$	0		0.992
X_{91}	$\mathbf{M}w_{b\_D,c\_D}$	0		0.992
X_{92}	$\mathbf{M}w_{c\_D,d\_D}$	0		0.992

Fig. 7.20 (continued)

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