CARLETON UNIVERSITY

SYSC 5104

METHODOLOGIES FOR DISCRETE EVENT MODELING AND SIMULATION

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Contents

1.0 Modeling Employees Behavior in Workplace Dynamics Using Cell-DEVS

1.1 Introduction

Based on the "Simulation of Employee Behavior Based on Cellular Automata Model" article referenced in [1], a cell-DEVS model was implemented. This cell-DEVS model is called EmployeeBehaviour and it focuses on the complex behaviour of employees in a workplace. "Employee behavior which is encouraged and propitious to the management, production, creation and cooperation of the organization, could be called Positive Behavior (PB), such as invention of technology, retrenchment of resource; employee behavior which is the behavior not encouraged, forbidden by the rule or the culture of the organization, could be called Negative Behavior(NB), such as privilege abuse and theft; and Zero Behavior(ZB), between Positive and Negative, is neither encouraged nor forbidden. ZB may be the leak of the rule, or is not heavy to such an extent that the object can be punished, such as absenteeism, substance abuse; it may be inaction, such as do-nothing behavior." [1] Organizations in general put in place encouragement policies to encourage Positive Behaviour and punishment policies to restrict Negative Behaviour.

1.2 Employee Behaviour Model Definition

The definition of the EmployeeBehaviour model is provided below:

1. The workplace will be modeled using a 15x15 array, where 225 (15*15) is equal to the number of employees. In addition, the cell space of the model represents the workplace.

2. The EmployeeBehaviour model is a three-dimensional model which has 3 planes. Each of the planes contains information about the employees. Plane 0 is the Employee Behaviour plane, Plane 1 is the Influence Plane and Plane 2 is the Insistence plane. Note that influence and insistence are characteristics related to employee behaviour.

3. The three planes are described below.

- Plane 0: Employee behaviour – In this plane, each cell or employee can have 3 states: -1, 0 and +1. 1 is the Positive Behaviour (PB), -1 is Negative Behaviour (NB) and 0 is Zero Behaviour (ZB). Employee Behaviour is affected by Influence and Insistence. Each cell in Plane 0 will have a Moore's neighborhood with 25 cells in plane 0, a Moore's neighbourhood with 25 cells in plane 1 and just its corresponding cell in plane 2. A diagram showing the neighborhood of each cell in plane 0 is given in Figure 1 below.
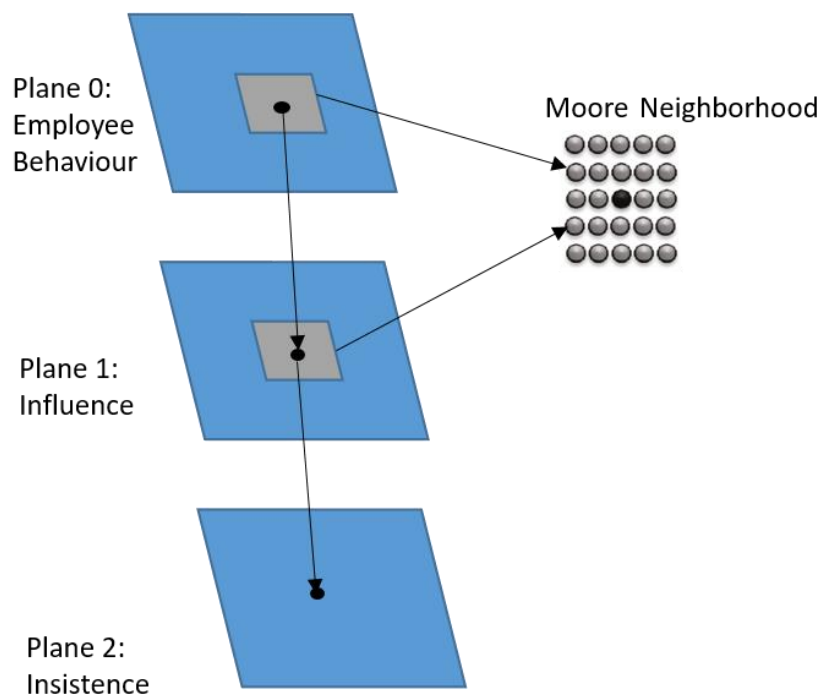

Figure 1: Neighborhood of cells in plane 0

- Plane 1: Influence (INF) - "Influence is the extent that some employee affects his neighbors." [1] Each cell in the influence plane can have values 1, 2 or 3 and this value represents the degree of influence the corresponding employee in plane 0 has. Value 1 means that a cell has little influence on its neighbors, value 2 means that a cell has medium influence on its neighbors and value 3 means that a cell has a large influence on its neighbors.

- Plane 2: Insistence (INS) – "Insistence is the extent of the employee's holding his own behavior. A High-Insistence employee cannot be easily affected by his neighbors." Each

cell in the insistence plane can have values 1, 2 or 3 and this value represents the degree of insistence the corresponding employee in plane 0 has. Value 1 means high-insistence (cannot be easily affected by his neighbors) and value 0 means low insistence (can be easily affected by his neighbors).

Note that the values of the cells in the insistence and influence planes are constant and are not changed as time progresses.

"Different neighbor behavior makes different influence to the cell. The cumulate influences of PB, NB, and ZB neighbors on one given cell are separately called Positive, Negative, and Zero Environmental Disturbances Degree, which are abbreviated as ped, ned and zed respectively." [1]

From [1], ped, ned and zed are defined as follows:

$$ped_{i,j}^t = \sum_{i'=i-2}^{i+2} \sum_{j'=j-2}^{j+2} \frac{INF_{i',j'}}{\sqrt{(i'-i)^2+(j'-j)^2}}, S_{i',j'}^t = 1 \qquad \text{Equation 1} \qquad [1]$$

$$ned_{i,j}^t = \sum_{i'=i-2}^{i+2} \sum_{j'=j-2}^{j+2} \frac{INF_{i',j'}}{\sqrt{(i'-i)^2+(j'-j)^2}}, S_{i',j'}^t = -1 \qquad \text{Equation 2} \qquad [1]$$

$$zed_{i,j}^t = \sum_{i'=i-2}^{i+2} \sum_{j'=j-2}^{j+2} \frac{INF_{i',j'}}{\sqrt{(i'-i)^2+(j'-j)^2}}, S_{i',j'}^t = 0 \qquad \text{Equation 3} \qquad [1]$$

Where i' and j' are indices for the neighborhood of each cell, i and j represent the cell of interest. Consider ped; $INF_{i',j'}$ represents the influence of cells in the neighborhood that have a state or employee behavior with a value of 1 or for which $S_{i',j'}^t = 1$. The same applies for ned and zed.

The set of rules determined in [1] to estimate the change of employee behavior (cells in Plane 1) are given in Figure 2 and Figure 3. Note that the change of employee behavior is dependent on the influence and insistence of the neighborhood.

We define local rules:

(1) When $S_{i,j}^t = 1$, if $ped + INS_{i,j} = \max\{ped + INS_{i,j}, ned, zed\}$, then $S_{i,j}^{t+1} = 1$; else, if $ned > zed$, then $S_{i,j}^{t+1} = -1$; if $zed > ned$, then $S_{i,j}^{t+1} = 0$; if $zed = ned$, then $P\{S_{i,j}^{t+1} = 0\} = 0.5$, $P\{S_{i,j}^{t+1} = -1\} = 0.5$.

Figure 2: Rules to change Employee Behaviour in Plane 1 [1]

(2) when $S_{i,j}^t = -1$, if $ned + INS_{i,j} = \max\{ned + INS_{i,j}, ped, zed\}$, then $S_{i,j}^{t+1} = -1$;

else, if $ped > zed$, then $S_{i,j}^{t+1} = 1$; if $zed > ped$, then $S_{i,j}^{t+1} = 0$;

if $ped = zed$, then $P\{S_{i,j}^{t+1} = 1\} = 0.5$, $P\{S_{i,j}^{t+1} = 0\} = 0.5$.

(3) When $S_{i,j}^t = 0$, if $zed + INS_{i,j} = \max\{zed + INS_{i,j}, ped, ned\}$, then $S_{i,j}^{t+1} = 0$;

else, if $ped > ned$, then $S_{i,j}^{t+1} = 1$; if $ned > ped$, then $S_{i,j}^{t+1} = -1$;

if $ped = ned$, then $P\{S_{i,j}^{t+1} = 1\} = 0.5$, $P\{S_{i,j}^{t+1} = -1\} = 0.5$.

Figure 3: Rules to change Employee Behaviour in Plane 1 [1]

"An employee will strengthen his behavior intensity when the organization policy encourages the relative behavior, and reduces his behavior intensity when the organization policy forbids the relative behavior. In order to find how the policy affects the employee behavior, consider the following rule." [1] Equation 4 and Equation 5 show the definitions for ped and ned for an organization which enforces an encouragement policy or/and a punishment policy respectively.

When the organization encourages the PB of employee,

$$ped_{i,j}^t = \sum_{i'=i-2}^{i+2}\sum_{j'=j-2}^{j+2} \frac{\alpha * INF_{i',j'}}{\sqrt{(i'-i)^2+(j'-j)^2}}, S_{i',j'}^t = 1 \qquad \text{Equation 4} \quad [1]$$

When the organization punishes the NB of employee,

$$ned_{i,j}^t = \sum_{i'=i-2}^{i+2}\sum_{j'=j-2}^{j+2} \frac{\beta * INF_{i',j'}}{\sqrt{(i'-i)^2+(j'-j)^2}}, S_{i',j'}^t = -1 \qquad \text{Equation 5} \quad [1]$$

Where $\alpha \in R$, $\alpha > 1$, and $\beta \in R, 0 < \beta < 1$.

Where α is the encouragement policy factor and β is the punishment policy factor.

2.0 Formal Specification

The formal specification of the Atomic Cell-DEVS model has the form CD = < X, Y, I, S, θ, N, d, δint, δext, τ, λ, D >

Plane 0:

CD = < X, Y, I, S, θ, N, d, δint, δext, τ, λ, D >

$X = \{-1,0,1,2,3\}$

$Y = \{-1,0,1\}$

$S = \{-1,0,1\}$

N = neighborhood ={ (0,0,2), (-2,-2,0), (-2,-1,0), (-2,0,0), (-2,1,0), (-2,2,0), (-1,-2,0), (-1,-1,0), (-1,0,0), (-1,1,0), (-1,2,0), (0,-2,0), (0,-1,0), (0,0,0), (0,1,0), (0,2,0), (1,-2,0), (1,-1,0), (1,0,0), (1,1,0), (1,2,0), (2,-2,0), (2,-1,0), (2,0,0), (2,1,0), (2,2,0), (-2,-2,1), (-2,-1,1), (-2,0,1), (-2,1,1), (-2,2,1), (-1,-2,1), (-1,-1,1), (-1,0,1), (-1,1,1), (-1,2,1), (0,-2,1), (0,-1,1), (0,0,1), (0,1,1), (0,2,1), (1,-2,1), (1,-1,1), (1,0,1), (1,1,1), (1,2,1), (2,-2,1), (2,-1,1), (2,0,1), (2,1,1), (2,2,1)}

d = 100 ms (transport delay)

τ: N→S: as defined in EmployeeBehaviour.ma.

Plane 1:

CD = < X, Y, I, S, θ, N, d, δint, δext, τ, λ, D >

$X = \emptyset$

$Y = \{1,2,3\}$

$S = \{1,2,3\}$

N = neighborhood ={ (0,0,0),(00,-1)}

d = 100 ms (transport delay)

τ: N→S: as defined in EmployeeBehaviour.ma.

Plane 2:

CD = < X, Y, I, S, θ, N, d, δint, δext, τ, λ, D >

$X = \emptyset$

$Y = \{1,2,3\}$

$S = \{1,2,3\}$

N = neighborhood ={ (0,0,0),(00,-2)}

d = 100 ms (transport delay)

τ: N➔S: as defined in EmployeeBehaviour.ma

3.0 Implementation and Testing

3.1 Implementation

  The rules of the Employee behavior model are defined such that only the cells in plane 0 which represents the actual behavior of each employee changes. The influence and insistence values for each employee (plane 1 and plane 2 respectively) are always the same. However, note that the influence and insistence of a cell is used to determine the employee behavior of that cell (in plane 0). In addition, the model is defined such that if cell (0,0,0) represents an employee, the corresponding cell in plane 1 cell (0,0,1) is that employee's influence value and similarly the corresponding cell in plane 2 which is cell (0,0,2) is that employee's insistence value.

Note that a cell space of 225 cells (15 x 15) was used in this model. However, the cellular automata model in [1] uses a cell space of 10,000 cells. The reason a cell space of 225 cells was chosen is because a research paper in [2] which also models employee behavior using cellular automata used a 225 cell space to model a small medium enterprise (SME). Therefore, this size for the cell space was considered to be suitable for this assignment.

Other basic definitions for the model are given below:

```
#include(rules.inc)

[top]
components : EmployeeBehaviour

[EmployeeBehaviour]
type : cell
dim : (15,15,3)
delay : transport
defaultDelayTime : 100
neighbors : ... as defined in EmployeeBehaviour.ma
border : wrapped
initialvalue : 1
localtransition : EBehaviour-rule
initialCellsValue : EmployeeBehaviour.val
zone : insistence { (0,0,2)..(14,14,2) }
zone : influence { (0,0,1)..(14,14,1) }
```

The rules for the EmployeeBehaviour model are defined in *EmployeeBehaviour.ma*.

Recall that the Influence and Insistence planes basically remain constant and only the Employee behaviour plane changes. The rules for the Employee behavior plane are defined in Figure 2 and Figure 3. However, note the following differences:

- A portion of (1) in Figure 2 says:
  When $S_{i,j}^t = 1$, if ped + $INS_{i,j}$ = max{ ped + $INS_{i,j}$, ned, zed}, then $S_{i,j}^{t+1} = 1$;
  The above rule was simplified to the following:
  When $S_{i,j}^t = 1$, if ped + $INS_{i,j}$ >= ned AND ped + $INS_{i,j}$ >= zed, then $S_{i,j}^{t+1} = 1$;

  The simplified rule is approximately equivalent to the original rule.

- Similarly, for rules (2) and (3) in Figure 3,

  When $S_{i,j}^t = -1$, if ned + $INS_{i,j}$ = max{ ned + $INS_{i,j}$, ped, zed}, then $S_{i,j}^{t+1} = -1$;
  Becomes
  When $S_{i,j}^t = -1$, if ned + $INS_{i,j}$ >= ped AND ned + $INS_{i,j}$ >= zed, then $S_{i,j}^{t+1} = -1$;
  And

  When $S_{i,j}^t = 0$, if zed + $INS_{i,j}$ = max{ zed + $INS_{i,j}$, ped, ned}, then $S_{i,j}^{t+1} = 0$;
  Becomes
  When $S_{i,j}^t = 0$, if zed + $INS_{i,j}$ >= ned AND zed + $INS_{i,j}$ >= ped, then $S_{i,j}^{t+1} = 0$;

The formulas for ped, zed and ned were defined as macros in a file called *rules.inc.*

Employee behaviour plane has the following rules:

```
%Employee behaviour (Plane 0) rules
[EBehaviour-rule]

% If a cell has Positive Behaviour i.e. (0,0,0) = 1 the rules are as follows:
rule : {1} 100 { (0,0,0) = 1 and ( ((#macro(ped) + (0,0,2)) >= #macro(ned))
and ((#macro(ped) + (0,0,2)) >= #macro(zed)) ) }
rule : {-1} 100 { (0,0,0) = 1 and (#macro(ned) > #macro(zed)) }
rule : {0} 100 { (0,0,0) = 1 and (#macro(zed) > #macro(ned)) }
rule : {(-1)*randInt(1)} 100 { (0,0,0) = 1 and (#macro(ned) = #macro(zed))
}%next state is random integer which is either 0 or -1

% If a cell has Negative Behaviour i.e. (0,0,0) = -1 the rules are as
follows:
rule : {-1} 100 { (0,0,0) = -1 and ( ((#macro(ned) + (0,0,2)) >= #macro(ped))
and ((#macro(ned) + (0,0,2)) >= #macro(zed)) ) }
rule : {1} 100 { (0,0,0) = -1 and (#macro(ped) > #macro(zed)) }
rule : {0} 100 { (0,0,0) = -1 and (#macro(zed) > #macro(ped)) }
rule : {randInt(1)} 100 { (0,0,0) = -1 and (#macro(ped) = #macro(zed)) }%next
state is random integer which is either 0 or 1

% If a cell has Zero Behaviour i.e. (0,0,0) = 0 the rules are as follows:
rule : {0} 100 { (0,0,0) = 0 and ( ((#macro(zed) + (0,0,2)) >= #macro(ned))
and ((#macro(zed) + (0,0,2)) >= #macro(ped)) ) }
rule : {1} 100 { (0,0,0) = 0 and (#macro(ped) > #macro(ned)) }
rule : {-1} 100 { (0,0,0) = 0 and (#macro(ned) > #macro(ped)) }
rule : {power(-1,randInt(1))*1} 100 { (0,0,0) = 0 and (#macro(ned) =

#macro(ped)) }%next state is random integer which is either -1 or 1
```

Influence plane has the following rules:

```
%Influence (Plane 1) rules
[influence]
%Constant influence cells
rule : { (0,0,0) } 100 { t }
```

Insistence plane has the following rules:

```
%Insistence (Plane 2) rules
[insistence]
%Constant insistent cells
rule : { (0,0,0) } 100 { t }
```

3.2 Testing

The condition of the model during testing was made to match the cellular automata model in [1] which this model is based on. Based on the paper in this [1] reference, the Influence and Insistence are integers distributing uniformly in [1,3] and the proportion of PB (value of 1), NB (value of -1) and ZB (value of 0) is 1:1:1. The results of the cell-DEVS model and the cellular automata model were compared to see if the cell-DEVS model behaved as expected.

As a result, the initial values of the cells in Plane 0 were specified such that although the state of the cells look random, there is actually a 1:1:1 proportion of PB, NB and ZB states. Also, the initial values of the cells in the insistence and influence planes were defined such that the cells have values 1,2 and 3 distributed uniformly.

The initial values for the cell space is shown in Figure 4 below. The model was loaded on CellDEVS Simulation Viewer to produce the nice visual representation shown in Figure 4.
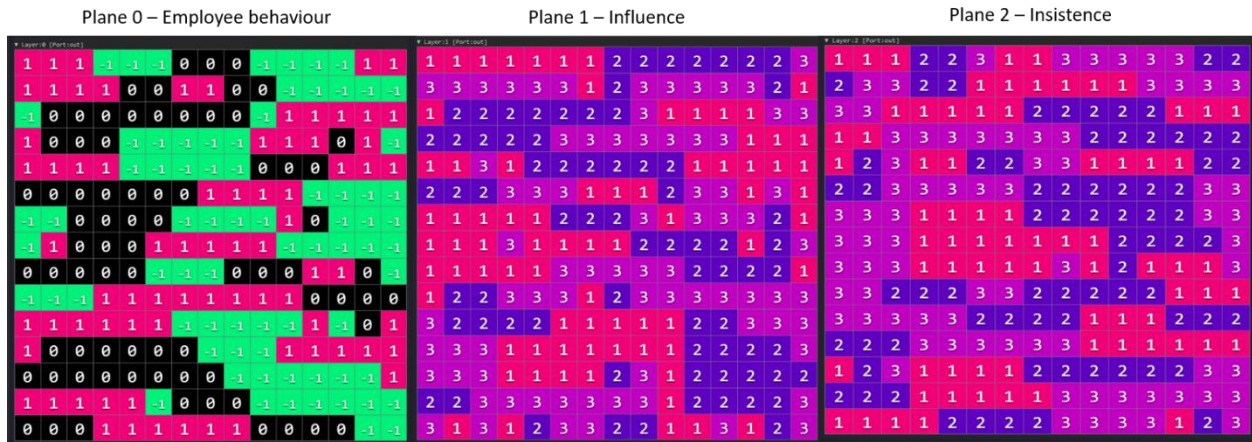

Figure 4: Initial Values of the Cell Space

Four tests were performed on the model using the same initial values in Figure 4. The initial values are stored in the file *EmployeeBehaviour.val*.

Test 1

The model was simulated using ped, ned and zed as defined in Equations 1, 2 and 3 respectively. In this test, no encouragement policy factor or punishment policy factor was considered. Note that ped, ned and zed are defined as macros in the file *rulesA.inc*. The log file for test 1 is stored in *EmployeeBehaviourLOG.log*

The state of the cell space at the end of the simulation period is shown in Figure 5 below. Note that the Influence and Insistence planes remain constant but the Employee behavior plane changes to mostly positive behaviour (PB) cells, some zero behavior (ZB) cells and no negative behaviour (NB) cells.
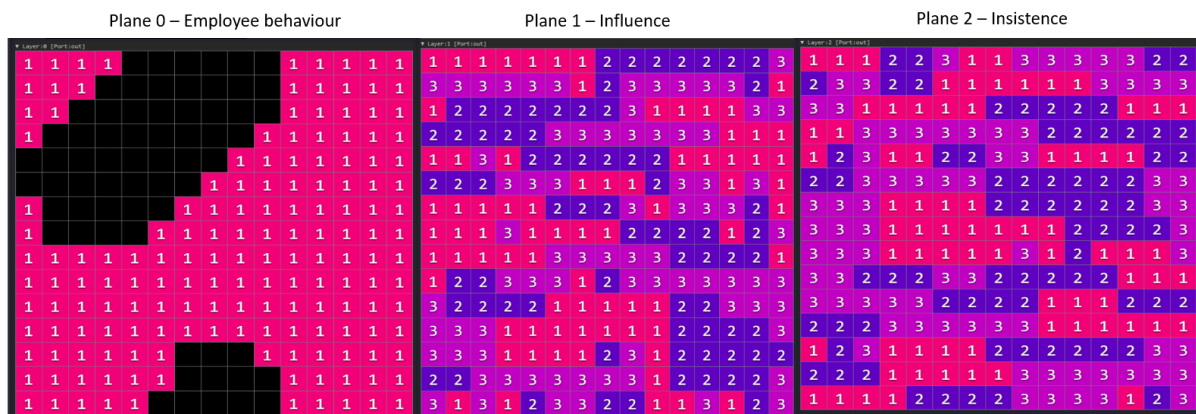

Figure 5: State of the cell space after simulation of test 1.

Test 2

The model was simulated using ped as defined in Equation 4 with $\alpha = 1.1$, while ned and zed are as defined in Equations 2 and 3 respectively. Note that ped, ned and zed are defined as macros in the file *rulesB.inc*. The log file for test 2 is stored in *EmployeeBehaviourLOG_1.log*.

The state of the cell space at the end of the simulation period is shown in Figure 6 below. Note that the Influence and Insistence planes remain constant but the Employee behavior plane changes to mostly PB cells, some ZB cells and no NB cells. Also note that there is some difference between Figure 5 and Figure 6 which is that the latter has more PB cells and less ZB cells (look at the yellow highlights in Figure 6). The purpose of including the factor $\alpha = 1.1$ into the definition of ped is to encourage positive behaviour. As we can see in Figure 6, the proportion of PB (state value of 1) is increased due to this encouragement policy factor.

In the cellular automata model in [1], it was found that the proportion of PB employee in test 2 is higher than in test 1. In the cell-DEVS models, the proportion of PB employees increase in test 2 compared to test 1. It is fair to say the since the PB increases in test 2, the model is behaving as expected.
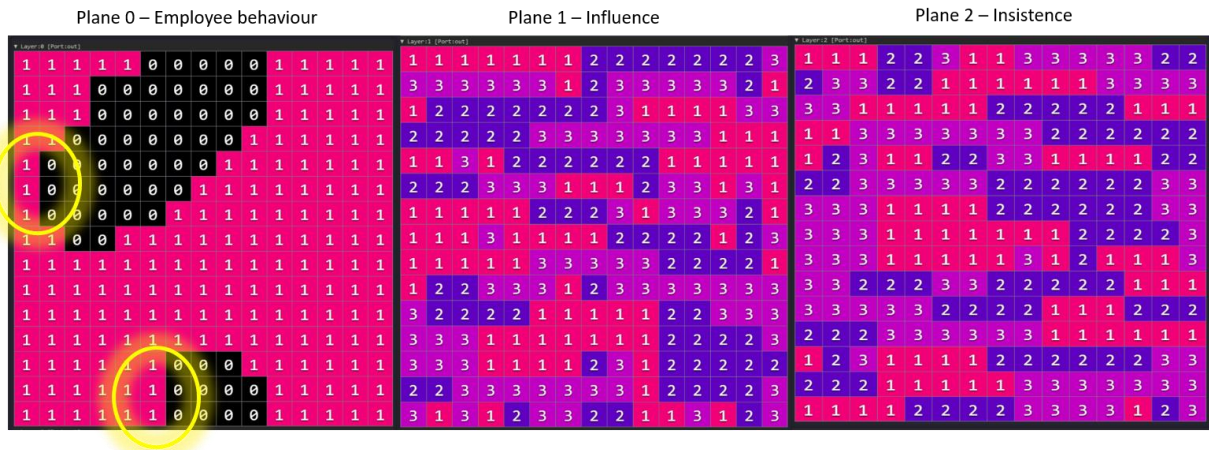

Figure 6: State of the cell space after simulation of test 2.

Test 3

The model was simulated using ned as defined in Equation 5 with $\beta = 0.9$, while ped and zed are as defined in Equations 1 and 3 respectively. Note that ped, ned and zed are defined as macros in the file *rulesC.inc*. The log file for test 3 is stored in *EmployeeBehaviourLOG_2.log*.

The state of the cell space at the end of the simulation period is shown in Figure 7 below. Note that the Influence and Insistence planes remain constant but the Employee behavior plane changes from its initial state in Figure 4 to PB cells, some ZB cells and no NB cells. Also note that the difference between Figure 6 and Figure 7 is that the latter has more '0' or ZB cells which are shown with the yellow circles in Figure 7. The purpose of including the factor $\beta = 0.9$ into the definition of ned is to discourage negative behaviour (NB). We can see that in this test, negative behavior is actually discouraged even though positive behaviour in this case is less than what we have seen in Figure 6. Note also that the cell space after the simulation is the same in test 1 (Figure 5) as it is in test 3 (Figure 7).

In the cellular automata model in [1], it was found that the proportion of PB employee in test 2 is much higher than in test 3 and the proportion of NB employees in test 2 is higher than in test 3 and the proportion of ZB employee in test 3 is even higher than that in test 1. In the cell-DEVS models, the proportion of PB employees is higher in test 2 than in test 3 (just like the cellular automata model), the zero behaviour in test 3 is higher than in test 2 but the proportion of ZB in test 3 is exactly the same as that in test 1. Note that there is no NB in the cell-space after the simulation. The cell-DEVS model was defined to have a cell-space of 225 cells (in order to model a Small Medium Enterprise), however the cellular automata model was defined to have a cell-space of 10,000 cells. Therefore, it is expected that the cell-DEVS model will provide limited information and that any discrepancies between the cell-DEVS model and the cellular automata model will be due to the sizes as well.

Test 3 shows some similarity between the cell-DEVS model implemented and the one in [1] and thus confirms that the cell-DEVS model is behaving as expected. Note that the .avi file which is in the simulation package for this model shows the results of test 3.
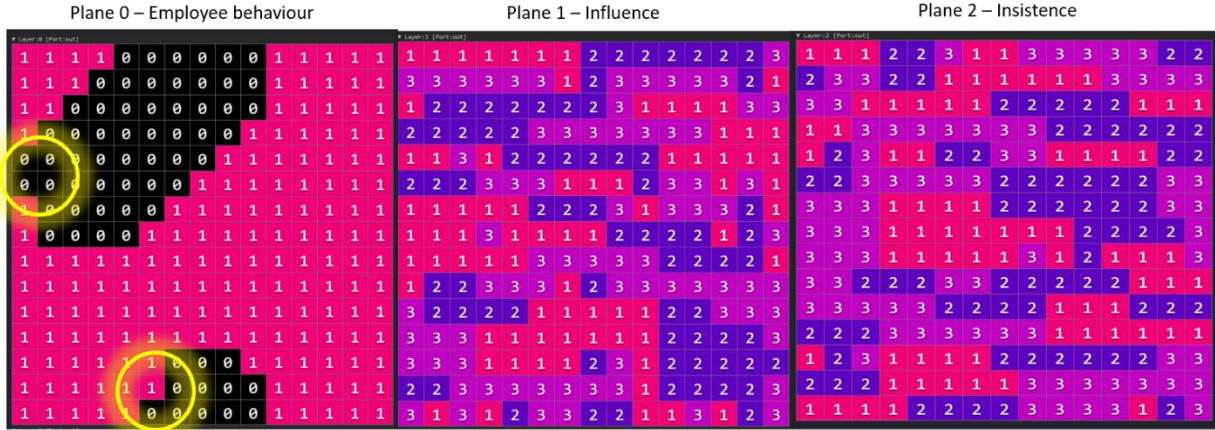
Figure 7: State of the cell space after simulation of test 3.

Test 4

The model was simulated using ped as defined in Equation 4 with $\alpha = 1.1$ and ned as defined in Equation 5 with $\beta = 0.9$, while zed is used as defined in Equation 3. Note that ped, ned and zed are defined as macros in the file *rulesD.inc*. The log file for test 4 is stored in *EmployeeBehaviourLOG_3.log*.

In this test, we check the effect of discouraging NB and encouraging PB simultaneously. The state of the cell space at the end of the simulation period is shown in Figure 8 below. Note that the behaviour of the cell space after the simulation is exactly the same as in test 2. Therefore Figure 6 and Figure 8 are all exactly the same while Figure 5 and Figure 7 are the same different. As explained previously, the cell-DEVS model was created to a smaller workplace (225 people or 225 cells) compared to the workplace of 10000 people in [1]. As a result, the information that can be obtained from the cell-DEVS model concerning the evolution of employee behaviour in the workplace is a bit limited.

The behaviour of the cellular automata Employee behaviour model shows that the proportion of ZB employee in test 4 is much lower than in test 3, the proportion of PB employee is the highest in test 4, and the proportion of NB employee is the lowest in test 4. In the cell-DEVS representation of the model, zero behaviour in test 4 is lower than in test 1 and 3 (just like

the cellular automata model) and like tests 1,2 and 3 there is no negative behaviour. Finally, the PB has a higher proportion in test 4 than in tests 1 and 3, but the PB is the same proportion in test 4 as in test 2.

Test 4 confirms that the cell-DEVS model behaves as expected but again the cell-space of the model limits the information obtainable from the results.
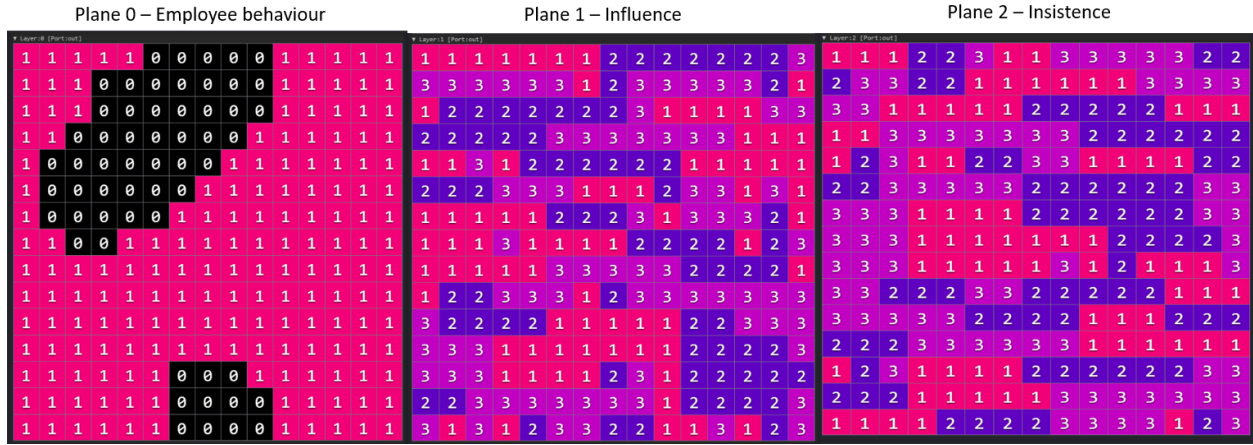

Figure 8: State of the cell space after simulation of test 3.

After concluding the tests for the model, one can say that the model is fairly correct. In general it was seen that enforcing the encouragement policy (tests 2 and 4) increased the proportion of PB cells which is the same behaviour as that of the cellular automata model. Any other discrepancies are due to the small size of the cell-DEVS model.

4.0 Conclusion

In this report, a cell-DEVS model is implemented based on the cellular automata model in [1]. The test cases used in [1] were also used to test the cell-DEVS model. After performing some simulations and tests on the model, it is fair to say that the cell-DEVS model is fairly correct as its behaviour matches the cellular automata model and any discrepancies are due to the small size of the cell-DEVS model. If the cell-DEVS model is improved to have a size of 10000 cell like that in the cellular automata model, it is very likely that its behaviour would be even much closer to that of the model in [1].

5.0 References

[1] Y. Jiao, S. Sun and X. Sun, "Simulation of Employee Behavior Based on Cellular Automata Model," 2007.

[2] P. Saravakos and G. C. Sirakoulis, "Modeling employees behavior in workplace dynamics," *Journal of Computational Science,* 2014.