Assignment 3: Model behavioral analysis

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# 1. Variable of interest

The variable of interest that has been chosen for this assignment is the stock variable ‘Planned infrastructure’. We chose this variable because of the different types of behaviour occurring over time. This makes this variable very suitable for the type of analysis we are applying in this assignment. We will first discuss the normal behavior of the variable of interest

Since the amount of available infrastructure at the start of the model is much larger than the infrastructure demand, no infrastructure will be planned until the infrastructure surplus empties and infrastructure aging causes new infrastructure to be planned, which occurs are around year 5.

Then exponential growth will occur as there is now a steep growth in the infrastructure shortage. A lot of infrastructure needs to be planned at the same time which causes this type of behaviour.

Next the ‘Planned infrastructure’ will slowly stop climbing as much, showing a logarithmic kind of behaviour. This is because the staff availability has become a limiting factor in the system and because of this there is not enough staff available to plan all the necessary infrastructure.

The ‘Planned infrastructure’ now starts to decline exponentially and then at the end logarithmically, as it is now showing goal-seeking behavior. The ‘Planned infrastructure’ stabilizes at 100Ml infrastructure planned per year which is the amount the limited amount of available staff members can plan.

The different types of behaviour are visualized in figure 1. The red line represents the ‘Planned infrastructure’ and the blue line is the second derivative of the ‘Planned infrastructure’ variable, normalized between -1 and 1. When the second derivative is positive it shows exponential behaviour and when it is negative there is logarithmic behavior.

Figure : Behavior of chosen variable 'Planned infastructure' (red) and the normalized second derivative of this variable (blue)

# 2. Setting up the analysis

We have selected the period of 0 to 20 years to perform the analysis on. We have chosen this period because in this period all the different types of behavior occur; linear, logarithmic and exponential. This period includes 5 intervals with different behaviors. We have chosen to include a relatively high amount of intervals because we are interested in analyzing the entirety of the behavior of this variable and not only parts of it. Furthermore, the period is bounded at 20 years because the last interval and type of behavior is still taken into account but since there are no other types of behavior during the entire model run it is easier to cut the period off at 20 years.

We have identified 4 candidate loops that we think will strongly influence the behavior of the ‘Planned infrastructure’ variable. The 4 chosen loops and many other loops influencing the chosen variable are visualized in figure 2.

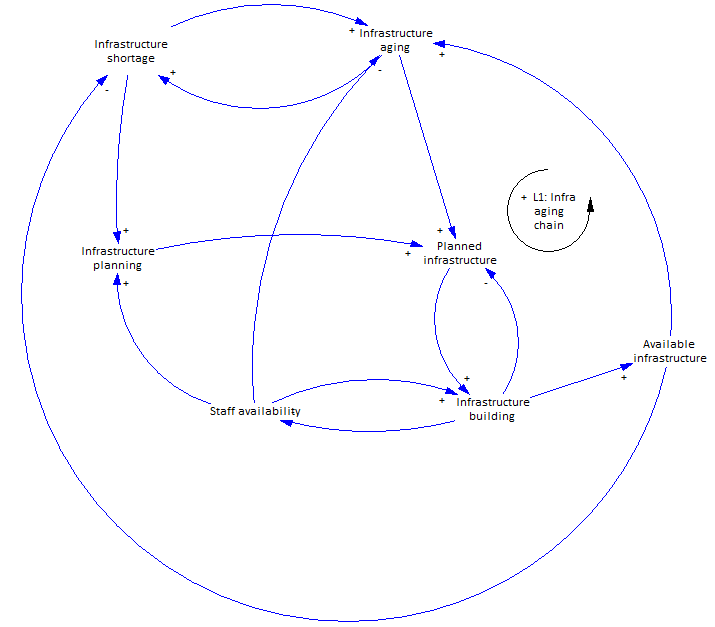


Figure : Four chosen candidate loops that influence the stock variable 'Planned infrastructure'

We have chosen 1 loop that shows the influence of infrastructure aging on ‘Planned infrastructure’. We chose this loop because the sensitivity analysis showed us that the planned infrastructure is relatively sensitive to infrastructure aging, in fact this relation turned out to be the most sensitive relation in the model, which is why we believe it could strongly influence the behaviour of the ‘Planned infrastructure’ variable. The next 3 loops all have to do with staff availability. We chose these types of loops because initial model testing showed that staff availability is a very important limiting factor in the model which also greatly influences the planning of infrastructure. We therefore believe these loops will strongly influence the behavior of the ‘Planned infrastructure’ variable. We will now give a summary of the four chosen loops.

Loop 1 lets the planning of infrastructure take into account the current aging of infrastructure. Loop 2 reduces the amount of infrastructure which can be planned due to limited staff availability. Loop 3 reduces the amount of infrastructure which can be built due to limited staff availability and loop 4 increases the infrastructure aging when less maintenance can be carried out due to limited staff availability which means more infrastructure needs to be planned.

# 3. Dynamic behavior hypothesis

This section will describe our hypotheses for the behavior of the “planned infrastructure” variable while disabling each of the earlier mentioned loops.

When we disable the aging of infrastructure, we would expect the direct effect on the planned infrastructure to be that it decreases, since fewer infrastructure will need to be built. However, we should also consider a secondary effect. Due to large infrastructure shortages in the baseline case, there isn’t enough staff available for planning all required infrastructure. Therefore, disabling the aging of infrastructure could also result in higher amounts of infrastructure being planned because there will be more staff available for planning. It is unclear which of these structures will affect the variable more.

When we disable the loop which requires staff members for infrastructure planning we expect to see a large increase in the planned infrastructure. Since the required infrastructure will never be built in the baseline case and because there is no feedback loop from the planned infrastructure stock to the planning of infrastructure inflow, we expect that the planned infrastructure will keep growing indefinitely. This could be considered as a structural weakness of the model.

Disabling loop 3 will deactivate the need of staff availability when building infrastructure. We would expect the behavior to be similar to the baseline, although the infrastructure shortage should be solved over time. Therefore, the planned infrastructure should decrease to 0 instead of a positive target value.

Disabling the effect of poor infrastructure maintenance on the infrastructure lifespan can once again have two effects. Due to there being less need for infrastructure construction we could expect the planned infrastructure to decrease. However, due to this lower need in infrastructure there is also more staff available for planning which could cause the planned infrastructure to increase. It is currently unclear which of these effects will be stronger.

# 4. Method of deactivations

The loops have been deactivated by removing the effect of infrastructure aging and staff availability respectively. For the first loop this means in practice that the equation of the infrastructure aging flow is changed from (Theoretical infrastructure capacity/infrastructure aging time) to (Theoretical infrastructure capacity/infrastructure aging time)\*(1-Turn of loop 1) so that when ‘Turn of loop 1’ equals 1, there is no infrastructure aging anymore. This way there is no such effect on the planning of infrastructure.

The second loop uses the same method to shut down part of the ‘infrastructure planning’ equation which includes the effects of staff availability on the planning of infrastructure. The third loop once again uses the same method but now in the equation of ‘build infrastructure’ to shut down the effect of staff availability on the building of infrastructure. The last loop uses the same method, but this time in the equation of ‘Effect of maintenance on aging time’ to make this equation equal to 0 so that maintenance no longer influences aging time.

We have chosen this method because by easily changing the value of the ‘turn of loop X’ variable from 0 to 1 from a certain time to test for the different intervals by using a PULSE function, we were able to shut off one loop for different intervals and see the change in behaviour compared to the baseline scenario.

# 5. Execute the Analysis

In this assignment Ford’s behavioral approach is used to perform a behavioral analysis of the model. The purpose of Ford’s behavioral approach is to identify feedback structures that dominate behavior. This is done by deactivating loops for each interval of atomic behaviour of the variable in question.

We have done this analysis by deactivating the loops at the start of each atomic behavior interval. The results will be discussed per interval below.

## Timeslot 1; turned off loop at t=0



Figure 3: Planned infrastructure for the baseline and for the turned off loops at t=0

The results of turning off the different loops at 0 years are shown in figure 3. We can see that loop 4 shows similar behaviour to the baseline although the time period of which is stabilizes is a lot longer. This behavior change results from the fact that the lifespan of infrastructure is increased due to the effect of poor maintenance not being taken into account, therefore there is more staff available for planning infrastructure which allows for a higher planned infrastructure.

The behavior of loop 3 deviates from the baseline because the building of infrastructure is not constrained by the availability of staff, therefore all planned infrastructure will eventually be built so the planned infrastructure can decrease to zero.

The behavior of deactivating of loop 2 might show a structural weakness in the model. The planned infrastructure increases infinitely since the planning of infrastructure (inflow) does not take into account the amount of infrastructure that is already planned (as it only takes into account the infrastructure shortage).

Switching off loop 1 results in infrastructure having an infinite lifespan. The step-like decline is caused by an oscillating behavior in the distribution of staff attention between maintenance activities and building activities. However in general, it shows similar behavior to the baseline as it also declines to a target value and stays there.

The main dominant loop in this scenario, when not considering loop 2 since it shows a structural weakness of the model, is loop 3.

## Timeslot 2; turned off loop at t=4.5



Figure 4: Planned infrastructure for the baseline and for the turned off loops at t=4,5

This graph shows the same behavior for all loops as in figure 3 when the loops were turned off at time = 0. This is because the model, with the current initial values of water demand and available infrastructure, shows an infrastructure surplus until approximately 5 years and the loops that we have chosen do not affect the model in case of sufficient infrastructure.

The difference in loop 1 (it starts increasing much earlier) compared to the behaviour in interval 1 is caused by the fact that the infrastructure surplus will remain for a longer time period if infrastructure aging is disabled from the beginning instead of only from t=4,5. When the loop is turned off at t=0 the increase in planned infrastructure is only caused by the infrastructure demand being higher than the infrastructure available whereas when the loop is turned off at t=4,5 the infrastructure has been aging during the first 4,5 years causing the planned infrastructure to increase at an earlier time since more will be needed.

The dominant loops here are loop 1 and 3 as they show different behaviour from the baseline assuming we do not consider loop 2 as it shows a structural weakness in the model. However, it could be argued that loop 1 is not dominant here as when the step-like decline is seen as a linear decline is shows similar behaviour to the baseline as it also declines to a target value and stays there.

## Timeslot 3; turned off loop at t = 6



Figure 5: Planned infrastructure for the baseline and for the turned off loops at t=6

Again the same behaviour can be distinguished in figure 5 where the loops are turned off at t=6. This is to be expected since in timeslot 2 until t = 6 the behaviour do not differ greatly from the baseline behaviour. Therefore, turning off the loops 1,5 years later should not influence behaviour much.

The behaviour of loop 1 is once again shifted to the left since there is 1,5 years more infrastructure aging.

The dominant loops here are loop 1 and 3 as they show different behaviour from the baseline assuming we do not consider loop 2 as it shows a structural weakness in the model. However, it could be argued that loop 1 is not dominant here as when the step-like decline is seen as a linear decline is shows similar behaviour to the baseline as it also declines to a target value and stays there.

## Timeslot 4; turned off loops at t=9



Figure 6: Planned infrastructure for the baseline and for the turned off loops at t=9

Figure 6 shows the behaviour of the baseline and when the different loops are deactivated at t=9. Loop 2, 3 and 4 again show the same behavior. However, loop 1 does show different behaviour as the step-like decline is now a gradual decline without a starting peak. Because the infrastructure aging stops at t=9, there is more staff is available because less infrastructure needs to be built and therefore more staff is available for infrastructure planning so the planning of infrastructure gradually declines over time as enough can be planned and build to deal with the infrastructure shortage. This causes the behaviour of deactivating loop 1 to gradually decline from t=9. There is no peak because the planned infrastructure is at equilibrium with the required infrastructure so the planned infrastructure does not need to grow / overshoot.

The dominant loops here are loop 1 and 3 as they show different behaviour from the baseline assuming we do not consider loop 2 as it shows a structural weakness in the model.

## Timeslot 5; turned off loops at t=12



Figure 7: Planned infrastructure for the baseline and for the turned off loops at t=12

Figure 7 shows the behaviour of the baseline and when the different loops are deactivated at t=12. The behaviour of loop 2, 3 and 4 is still the same compared to the earlier intervals. Loop 1 however does show different behaviour as not it undershoots before it converges to the target value. In the baseline scenario from t=12 there is no more staff available for the infrastructure since all staff members are needed to supply water from tankers. Because of the stop of aging of infrastructure, a large enough portion of the infrastructure survives so there is still some staff available for planning and building which makes sure there is still some infrastructure being planned. It undershoots because there has just been a peak in planned infrastructure which will then all be build, causing the decline in planned infrastructure and after a time period there is more infrastructure needed which causes the increase.

The dominant loops here are loop 1 and 3 as they show different behaviour from the baseline assuming we do not consider loop 2 as it shows a structural weakness in the model.

## Timeslot 6; turned off loops at t=13.5



Figure 8: Planned infrastructure for the baseline and for the turned off loops at t=13,5

Figure 8 shows the behaviour of the baseline and when the different loops are deactivated at t=13,5. At t=13,5 all the staff is working on supplying water through tankers so there is no possibility to work on infrastructure anymore, so there is no new infrastructure being planned. Because it already converged to its target value here, the different loops show no different behaviour. Loop 3 does show different behavior since that loop shut down the necessity of staff to build infrastructure so infrastructure can still be build, causing the planned infrastructure to decline to zero.

The dominant loops here is loop 3 as it show different behaviour from the baseline assuming we do not consider loop 2 as it shows a structural weakness in the model.

# 6. Discussion

In the dynamic hypothesis chapter it was mentioned that disabling the infrastructure aging loop can have two effects. It could either decrease the planned infrastructure since less infrastructure is required to be built. It could also increase the planned infrastructure due to there being more staff available for the planning task. The behavioral analysis has shown that this second effect influences the model more strongly so more infrastructure will be planned when disabling infrastructure aging.

We expected that disabling the loop which causes staff to be needed for planning infrastructure might show a structural weakness in the model. Since there is no feedback from the planned infrastructure stock to the planning of infrastructure inflow, the stock will keep growing infinitely. This was also shown in the behavioral analysis.

Disabling loop 3 (the need for staff availability for building infrastructure) should result in similar behavior to the base case with the exception that over time the planned infrastructure should reduce to zero. This is clearly shown in the behavioral analysis.

Disabling the effect of poor maintenance on infrastructure lifespan can once again have two effects. The first effect could be that there is less planned infrastructure due to less infrastructure is required to be built. The second effect could be that there is more staff available for planning due to less infrastructure construction being required. The behavioral analysis has shown that this last effect is stronger so the planned infrastructure will be higher than in the baseline.

There are several issues with Ford’s behavioural approach which mostly surface as model complexity increases.

First of all, in large, intertwined, models there are a lot of loops influencing a variable and many of these loops share a large portion of their variables. For example in this model, the variable of interest is affected by 265 loops. Therefore, it becomes virtually impossible to shut down single loops. Furthermore, shutting down a single loop is likely to have a very small effect in cases where loops share many variables. Therefore, all permutations of shadow loops will need to be checked which causes a combinatorial explosion of possibilities. When these effects are combined it becomes very time consuming and error-prone to analyze and interpret the results.