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Coflow Structures: Some Problems and Solutions In Representing Psychological Characteristics and Processes

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ABSTRACT

The coflow structure is useful when changes in one level simultaneously drive another set of changes in a second level. Coflow structures can represent how psychological variables, such as average attitudes, are carried over as a group of people change status or designation. In modeling a problem of an agency, we had difficulties using the classic form of the coflow process to represent average attitudes towards the organization. ***Total Attitude****, which is defined as a state variable, is hard to interpret. This is particularly true when attitudes are also influenced by organizational experience and may erode over time. This paper compares an isolated coflow structure with the coflow structure combined with an eroding process. Adding an eroding process to the classical coflow structure generated interesting behavior modes, such as logarithmic decline to a minimum and growth toward a higher equilibrium point.*

We suggest directly using ***Attitude*** *as a stock rather than using* ***Total Attitude*** *as the level. Changes in* ***(Group) Attitude*** *would depended on the influence of those coming in from the previous stage, experiences happening at that stage, and perhaps upon a naturally occurring eroding process. The influence of new people coming into the group affected* ***Attitude*** *in proportion to their numbers. If only a few entered the organization, their attitudes would have little effect on the group's* ***Attitude****. We suggest two alternatives to the classical coflow formulation. We also show how each formulation behaves when we allow attitudes to erode.*

INTRODUCTION

The coflow structure becomes very useful when some change or action in a fundamental level concomitantly causes a change in another level. For example, in modeling the production of computer code, one could also represent the generation of programming bugs by directly connecting the production of lines of code with the rate of bug generation. In addition, the coflow structure is frequently used to deal with the change in psychological, demographic, and social characteristics of people who are changing status, such as the change in the level of sophistication with new technology of new hires. In this case, the second level, which deals with the characteristic, is the total accumulation of the rate of change in the characteristic variable. To make sense of this, one has to divide the level by the number of people in the organization to obtain the <u>average</u> value of the psychological characteristic.

GOALS OF THIS PAPER

There is very little published about the coflow process. This paper will first point out some of the problems with using the classical approach to the coflow structure when the coflow dynamics are combined with other processes. These problems deal with the definition of the psychological variable being modeled. We shall introduce two alternative model formulations, both of which directly quantify the psychological variable as an average or mean value. Since the coflow process can frequently be combined with other processes, the second goal of this paper is to show some interesting behavior modes, which emerges when the coflow process is combined with other fundamental atoms of structure, such as a draining process. In some circumstances, one observes a parabolic growth process, followed by a collapse of the value of the characteristic variable associated with the original driving level.

BACKGROUND

(Figure 1 at end of paper)

It is best to describe the background concerning the problems we ran into in using the coflow structure in our modeling efforts. We were interested in modeling some of the problems encountered by an organization, which represented our university's effort in dealing with urban problems within the community. The work was being done by graduate students majoring in a number of different areas of social science and natural resource management. Our modeling effort focused on the conflict the workers were experienced when they devoted so much time to helping people in the community at the expense of their own graduate careers. As part of the modeling process, we wanted to represent the students' attitudes toward the Center as they came into the organization and also spent time working for the Center. At first, before actually working for the Center, they came into employment with a much more positive attitude than after spending some time working on some project in an urban setting. Figure 1 shows a simplified version of part of the model, which deals with the number of students recruited and various ways in which their attitudes might be influenced in this situation.

As one can see, the coflow process in our model is also supplemented with other structures which capture (1) the external influences on attitudes from the experience in the Center and (2) the spontaneous erosion of attitudes over time. To amplify a bit, attitudes can be influenced in many ways. The coflow process in our model focused on how attitudes were modified by newcomers who had come in with a strong positive feeling about the Center before they actually began to work for the organization. On the other hand, we felt that experience on the job would also have a profound effect on people over time. Finally, we assumed that extreme values were relatively hard to maintain, and thus we put in a draining process to represent spontaneous decreases in the worker's attitude.

SOME BASIC PROBLEMS WITH THE CLASSIC COFLOW STRUCTURE

It can be seen from Figure 1 that the level representing the psychological characteristic, which in this case are the attitudes of the trainees and workers, is in total attitude units. This number is relatively meaningless, until one uses an additional converter or auxiliary variable, Av_Trainee_Att, which can easily be quantified on a scale ranging, for example, between –100 and + 100 points. In terms of units, Av_Trainee_Att is equal to Total_Trainee_Att units/ People. Changes in that variable would describe mean behavior over time.

The fact that the level itself is not interpretable is problematic. Although there are many examples of good SD models in which levels have to be modified through converters, in general, levels should be defined to be a interpretable and meaningful as possible. State variables can be defined as those variables which are monitored by the actors or stakeholders in any given situation. The problem of defining attitudes as total attitudes leads to some difficulties. For example, from Figure 1, we see that attitudes are influenced by the workers experience in the Center. The change in Tot_Wkr_Att is accounted for partly from rate variable, Wkr_Experiences. The units of this rate variable have to be in total attitude units per unit of time. It is extremely difficult to calibrate and work with these units. It would be better to define the level as an index of average behavior for the group. Thus, instead of having the average attitude defined as a converter, the average attitude would be defined directly as a state variable or level concept. Eventually, we shall do this later in the paper.

THE BEHAVIOR OF THE CLASSICAL COFLOW STRUCTURE

(Figure 2 at end of paper)

The Simple Case First

To simplify matters somewhat, Figure 2 shows an even more simplified version of the classical coflow structure. In this case, there is only one set of workers in which increases through recruiting and decreases through quitting or retiring. The characteristic is the Total_Wkr_Att, which is the summation of the workers' attitudes towards the organization. In the classical version of the coflow process, the average worker attitude is an auxiliary variable, which in this case is Av_Wkr_Attitude. Note from Figure 2, we have modeled the worker sector as a first order material delay by specifying the rate of leaving the Center is a function of the number of workers. This is a drainage process.

(Figure 3 at end of paper)

Basic Results

Run #1. For the entire series of simulation runs, we assume one can quantify average attitudes toward the Center on an attitude scale which runs from –100 to +100, zero being neutral. In our base run, we started the Center with a single worker and recruited people per month. The average stay in the Center was for one year or twelve months. The initial total attitude level was 40, and with only one worker at the start of the run, the average attitude was 40 as well. Finally, we initially assume that incoming people are much more positive about the Center than those who have been there for some time. Thus, we set the initial average attitude value of the incoming recruits (IncomingAtt) at a value of 75. We would interpret this as being very positive.

The initial run, as seen in Figure 3, indicates that the Workers show logarithmic growth pattern, a result which is well known, because we have modeled the level as a first order material delay. In this particular run, when the input rate equals 4 people per month and the time constant associated with Outrate equals 12 months, Workers will come to an equilibrium point at 48 people. Note also that the mean attitude, i.e., Av_Wkr_Attitude, shows the same pattern as material delay representing the number of people working at the Center.

Adding a Drainage Process to Total Attitudes

(Place Figure 4 at end of paper)

Run #2. Thus far the behavior of the model displays fairly well known behavior. For example, if the initial attitudes of the workers were above 75, say 83, the average attitude would decrease over time to the value of 75. Frequently, however, other influences on attitudes besides from the effect of new people entering the organization also have to included in the model. One such process deals with the gradual decay or decline of attitudes. Satisfaction and positive attitudes have to constantly be maintained and fostered to prevent erosion of these psychological variables. Let's this additional process into the model in addition to the original coflow process. Figure 4 shows the augmented model which includes a draining process to represent the erosion attitudes.

(Place Figure 5 at end of paper)

In run #2, we open the draining process and set the TimeToErode_Att, the constant associated with draining process to four months, implying that workers' positive attitudes decay relatively quickly. Figure 5 shows what happens to the three major variables in this situation. Again Workers show the characteristic logarithmic pattern over time. This is to be expected because it is not affected at all by the attitudes. Note also that Total_Wkr_Att has the same general pattern. However, looking at the third variable, Av_Wkr_Att , which is the average attitude toward the Center, one sees a new pattern emerging, namely logarithmic or parabolic growth, followed by overshoot and collapse to an asymptote. In this run, average attitudes fell below the initial value, name 40 attitude units. Note that this pattern is not the same as the usual s-shaped growth, overshoot, and collapse mode, frequently found and modeled by system dynamicists in a number of other situations .

This behavior pattern is relatively different from what might be expected. In many situations, a draining process would yield a simple and gradual steady state error. In this situation, there is overshoot. Note also that only the average attitude value has this pattern. The components of the mean curve show a different pattern, unlike the case where there is no spontaneous draining process, run #1.

These results seemed somewhat surprising to us. Our first thought was that somehow the pattern observed was an artifact of the computer integration process. We re-ran the simulation, with an extremely small dt, and Powersim's Runge-Kutta 4 (Variable) algorithm. The results were exactly the same. Indeed, all simulation runs reported here use the RK4 (Variable) approach to deal with a potential stiff system.

(Place Figure 6 at end of paper)

Run # 3. The last run showed that the average attitude first went up and then came down below its starting point. The time constant, TimeToErode_Att, was set at four months. In the next run, we changed the constant to 60 months to slow down the process. Figure 6 shows the results for the mean attitude only since the same logarithmic pattern appeared again for the other two variables. In this situation, the general pattern of log growth, overshoot and then decrease to an asymptote occurred again, but less vigorously. The negative loop was less strong, as would be expected when the constant was 60 months instead of four months. Nevertheless, the overall pattern persisted.

The Effect of Excess Workers

Run # 4. In the previous runs, we started with a very few workers, far below the equilibrium point, 48 people. In the next run, we kept the total attitude value at 40 units, but changed the number of workers from 1 to 100 people working for the organization. The average attitude value equaled .4 for this run, indicating that, as a whole, the workers were almost neutral about the organization at the beginning of the run..

(Place Figure 7 at end of paper)

As one can see from Figure 7, workers can down to an asymptote of approximately 48 people. In this run, Av_Wkr_Attitude (Figure 7c) showed the same logarithmic pattern as the classical case without the draining process. The only difference is that Figure 7C shows a steady state error. The average attitude starts at a low point and grows logarithmically to a steady state error. There is no evidence of overshoot under these conditions. At this point, we have two distinct behavior modes.

When Initial Workers and Average Attitude are Above their Equilibrium Points

(Please place Figure 8 at end of paper)

<u>Run # 5</u>. Thus far, we have seen that average attitudes either reach their asymptotes smoothly or overshoot first before reaching an equilibrium point. In this run, we again set the initial value of Workers at 100 people, but this time we set the <u>Total_Wkr_Att</u> at 4000 units, making the average attitude equal to 40 instead of .4 as in our last run. The results of this run, found in Figure 8, indicate that, although both the <u>Total_Wkr_Att</u> variable and the number of workers came down smoothly, the average attitude decreased to a minimum value which was less than the final equilibrium point. This is the mirror image of the pattern of run #2, which showed the pattern of log growth, overshoot, and collapse down to an asymptote.

When Workers Are Below Their Asymptote and Attitude Starts Above its Asymptote

(Please place Figure 9 at end of paper)

<u>Run #6</u>. In the next run, we set the initial number of workers at 20 and the <u>Total_Wkr_Att</u> value at 800, giving us an initial value for the average attitude of 40 attitude units. Setting parameters in this manner insured that the initial number of workers would be below its asymptote of 48 and the average attitude would be above its final asymptote. The results are shown in Figure 9. One can see from Figure 9C that the average attitude went down to its final equilibrium point in a standard manner. Unlike Run #4, there was no evidence of a "dip" before reaching its asymptote.

A Four-fold Summary of Findings

(Please place Figure 10 at end of paper)

Thus far we have shown a variety of behavior modes of the mean worker attitude, generated when studying the effects of both the classical coflow structure and another process which represents the spontaneous loss of positive worker attitudes. There are some rules of thumb which help us know under what conditions one would obtain simple logarithmic behavior and when one would predict either a pattern of growth, overshoot, and collapse or a pattern of dropping, dipping , and then increase to a higher asymptote.

<u>Setting initial levels and estimating final equilibrium points</u>. The variables of interest in our analysis are (1) the number of workers and (2) average worker attitude. This model containing the draining process consists of only two state variables, and is quite easy to estimate, given the value of the parameters, where the variables will be at equilibrium. We can use those estimates to develop our categorization scheme, which describes the conditions which generate specific behavior patterns.

Figure 10 summarizes these rules of thumb by means of a four-fold table. The rows represent the whether initially, the number of workers were above or below the equilibrium point, namely 48 workers in this situation. The columns represent whether the initial average attitude was below the maximum or minimum value. Runs # 2 and 3, started with workers being set at one person, far below the equilibrium point for workers, namely 48 persons. The Av_Wkr_Attitude in these runs was below its maximum. This generates a growth, overshoot, and collapse trajectory.

On the other hand, if again the initial number of workers is below its maximum, 48, but this time the average attitude starts above its minimum value, then we get the pattern in Panel 10-B.

If the system was started with a large number of workers, above the equilibrium point, which in this case was 48 persons, and the initial average worker attitude was lower than its maximum, then the logarithmic pattern emerged over time. This can be seen in Panel 10-C.

Finally, if both the initial number of workers and their attitudes were above their respective minimums, then the trend was downward, "undershoot," and up to an equilibrium point. This can be seen in Panel 10-D.

Thus, from panels 10A and 10D, one can see that, when the initial values of the variables are below their maximums, transient overshoot or undershoot occurs.

From Equilibrium Conditions: Changing TimeToLeave

In all the previous simulation runs, we started out of equilibrium. We next performed a series of simulation runs starting in equilibrium. We either changed the parameter on the drainage process associated with Workers or changed the parameter of the drainage process associated with Total-Wkr_Att.

Run #7 (Baseline Equilibrium). We first will look at the classical coflow structure when the drainage process representing spontaneous decreases in average attitude is turned off. We set the number of workers equal to 48, the equilibrium value for Workers. In addition, we set the equilibrium value of the second level, Total Attitude equal to the value of the IncomingAtt, which equaled 75 on the attitude scale. In this run, we wanted to see what would happen if we changed the time constant, TimeToGo on the material delay from 12 months to 18 months. This should take both levels out of equilibrium to a new set of values. What would happen to the average attitude, Av_Wkr_Attitude, which is the ratio of the two levels?

(Place Figure 11 at end of paper)

Panels 11-A and 11-B indicate that, when the time constant associated with first order material delay is changed from 12 to 18 months, the levels responded as they should, namely to increase in both cases. However, note that once the average attitude was in equilibrium, it never changed its value. This was because both the numerator and the denominator of the ratio defining the mean attitude changed by the same proportion. The transfer rate of the total attitude level, is a common function of the Outrate variable.

(Please Place Figure 12 at end of paper)

Run #8 (equilibrium with draining process). In this run, we started the simulation under the previous conditions, which were set for the classical coflow process without the draining actively engaged. At time 10, two things happened. First the switch for starting the drain process was turned on. Second, the time constant for the material delay, Workers, was changed again from 12 to 18 months. Figure 12 shows that, unlike the previous run, Average Attitude responded to the drain process and went smoothly to a new low equilibrium point.

From Equilibrium Conditions: Changing TimeToErode_Att

(Place Figure 13 at end of paper)

Runs #9 and #10 (equilibrium with draining process). The next two runs were conducted in a way which, after, starting both levels in equilibrium, the time constant associated with the draining process, TimeToErode_Att was changed to either a larger or smaller value at Time 10. Initially the value of the parameter was 10 months. Then, at Time 10, the value of the time constant was changed either up or down by six units.

The results of these two equilibrium runs can be seen in Figure 13. One observes that, when the changes in the constant associated with the negative, draining loop are initiated, the average attitude goes smoothly to a new asymptote. There was no sign of overshoot or going below the final asymptote, which was found under some conditions seen in Figure 10.

DEFINING AVERAGE ATTITUDE AS A STOCK VARIABLE

One of the initial concerns of this paper dealt with the problems of working with the classical coflow process by defining the level as the total attitude, when actually it is the average attitude that is most meaningful. The average attitude is what one wants to monitor in this situation. In the classical case, one has to define the average as a auxiliary variable, which would be the ratio of the total variable and the number of cases or people in the organization. We would like to suggest two related solutions to this problem. We first developed a solution in working on a model of dynamic problems of the Center For Urban Affairs (Levine, et al, 1998). Although it worked, we were modified it slightly to be more consistent with respect to dimensional analysis. In the meantime, we recently became familiar with another solution to this problem, worked out independently by Professor James Hines at M.I.T.[1] His solution was simple and elegant. In this paper, we shall refer to his version as the Hines Coflow structure. In addition, we will also describe our solution to defining average attitude directly as a level. The two solutions are very similar to each other. Ours is a bit more disaggregated and consequently less simple the the Hines coflow process.

(Please Place Figure 14 at end of paper)

The Hines Coflow Model

Figure 14 shows a version of the Hines coflow process with an additional draining process to represent spontaneous loss of the intensity of the workers attitude toward the organization. Note that the stock is principally modeled as a stock adjustment process or first order information delay. Second, in this approach, one forms the ratio of the number of workers to the RecruitRt. This ratio, dimensionally is in terms of time units, so that it can become a key input into the stock adjustment process. Mathematically it is equivalent to the classical version of the coflow process.

Results of Runs Without Draining Process

(Please Place Figure 15 at end of paper)

Runs #11 to #14 (Hines coflow model with draining process). Figure 15a and 15b show the results of runs, where initially, the average attitude value was above and below the goal. There is no surprise behavior here. The Hines coflow model gives identical results as the classical case.

The next set of runs were conducted with a combination of the coflow and draining process, by setting the switch, SW1 to a value of 1. Figure 15-C to 15-F show the identical results in each of those which resulted in previous runs associated with the classical case when we added a spontaneous drain on the attitudes (see Figure10).

In summary, the Hines solution to the problem seems strictly comparable to classical case. The overshoot and undershoot observed previously also were observed in approach as well.

A Disaggregated Coflow Model

We were unaware of the Hines alternative formulation of the coflow process when we solved the problem of how people take their beliefs and attitude with them entering and leaving organizations. In the past, the senior author had modeled attitude and belief systems using stock adjustment processes (Hunter et al, 1984). As indicated earlier in this paper, the coflow process can represent the influence of new people coming into an organization. Originally, we too worked with the ratio of workers to the input rate. However, since we were focusing on attitude change, where other independent sources of change have an effect on attitudes, we felt the time factor should represent the individual difference parameter dealing with how perusable people who were coming into the organization might be over time. We wanted to treat the coflow process independently of persusibility.

In order to accomplish this, we thought about the relationship between the number of new recruits and their influence on the mean worker attitude value over time. We assumed that if only a few new people came into the organization, they would not have too much influence on the group as a whole. On the other hand, a large number of new people might have a very big effect on attitudes, beliefs, and behaviors over time. We accomplished this by disaggregating workers into two groups, “trainees” and “older workers” respectively. Although we could have disaggregated attitudes into trainee attitudes and old worker attitudes, to be comparable with the two previous models, we decided to present the influence of new people on a single stock variable, namely average Worker Att.

(Place Figure 16 at end of paper).

The model is represented in Figure 16. The attitude sector of the model is almost identical to Hines Coflow process. The worker sector is represented by a second order material delay process, composed of trainees and workers. In order to make things a bit comparable from a parameter perspective, we set the time constant for training equal to 4 months and for the time to serve as a worker at a value of 8 months, make the total time equal to one year.

The primary change in worker attitudes was modeled as a stock adjustment process, which is similar to the Hines coflow approach. This change is proportional to the relative number of newcomers coming into the organization. We assume that, if the agency were to bring in a large number on new people, relative to the number of existing workers, they would have an important effect on worker attitudes. On the other hand, if just a few people come into the organization, they would not affect average attitudes very much.

Note that we have included a draining process in the model as before to see if one gets the same set of patterns as was found in the first two models.

(Place Figure 17 at end of paper)

Run #15 (disaggregated model, no draining process). In this situation, we wanted to see how this alternative to the coflow model behaved when there was <u>no drain process</u> active. We set the parameters as close as possible to those used in the other two coflow models. Thus, the constant, TimeToChng, was set at Two months. Figure 17 shows the results of this baseline run. The behavioral patterns for both the Worker and Av_Wkr_Att Variable were comparable to the patterns found for both the classical and Hines coflow models. For example, the total number of employees, i.e., trainees and workers, equaled 48 and the average attitude reached 75 in about the same time as the previous simulation runs.

Setting Trainees At Equilibrium.

(Please Place Figure 18 at end of paper)

Runs #16 to #19 (Disagregated model with draining process). The next series of runs were performed by first setting the initial value of the number of Trainees at 16, which is the equilibrium value under these conditions. We next undertook four simulation runs, where Workers were either above or below the equilibrium point, 48 people and Worker_Att was either above or below a maximum or minimum as before. The results are seen in Figure 18. One can see that these patterns match the classical and Hines coflow models very well. The three models appear to generating identical modes of behavior.

Setting Workers At Equilibrium.

(Place Figure 19 at end of paper)

Runs #20 to #23 (disaggregated model with draining process). The next series of four runs set Workers at 32, the equilibrium point, and allowed the Trainees and

Worker_Att variables to vary in the same way as before. Figure 19 shows these results. Again, the patterns found in each of the panels is similar to what was found before. Cells A and D show either overshooting and collapse toward a equilibrium point or in Cell D, Worker-Att first drops and then hits a minimum before reversing direction and rising to an equilibrium point.

MOVING TOWARD INSIGHTS

(Place Figure 20 at end of paper)

There were two goals to the paper, namely (1) describing and dealing with the problem of indirectly defining the average characteristic in the coflow process and (2) seeing the implications of combining the coflow structure with other mechanisms, such as a draining process. With respect to developing an alternative to the classical coflow structure, both the Hines approach and our disaggregated model appear to directly focus on an average psychological characteristic, such as the mean attitude toward an organization held by new people coming into the company. The difference between the two alternative formulations appears to be minimal. The Hines model is simple and to the point. Our formulation adds to the complexity of the modeling process, which at times is not conducive to understanding. On the other hand, if the problem being modeled calls for more detail, so that one should disaggregate the total workers into subgroups, then our formulation would be appropriate.

Illustrating the Structural Aspects of These Behavioral Patterns.

The four-fold table of patterns showed some somewhat surprising modes of behavior which appear to be replicable with all three models. Given the time restraints and the length of this paper, we shall only begin to move in the direction of analyzing the influence of loop structure on the patterns observed in this study. Figure 20 shows the loop structure of the classical coflow and the draining process. It can be seen that there are three negative loops involved in this situation. Again, as was mentioned previously, the worker's sector of the model drives the attitude sector of the model. There is no influence in the opposite direction. Loops B1 and B3 are associated with the draining processes related to a decrease in Total_Wkr_Att and Workers respectively. B2 represents another draining process, which is coupled with the coflow relationship between the OutRate variable and the TransferOfAtt rate variable.

In the model represented in Figure 20, one can find only two stocks and only three loops, yet the model exhibits a variety of behavior modes. System dynamicists have always been interested in gaining understanding about the dynamics of the problems being modeled by understanding the specific role of the loop structure in underlying the behavior of the model (Coyle, 1977; Richardson, 1995; Mojtahedzadeh, 1996, Ford, 1999).

An Example of Searching For Loop Dominance

To gain some insight concerning dynamics of combining the coflow and draining process, we are going apply a relatively new type of loop analysis, recently developed by Ford (1999), to one of the most interesting patterns described previously, name the pattern where the Av_Wkr_AA variable made a logarithmic drop down to a minimum, and then increased to a higher equilibrium point. This is the variable of interest in the analysis The the search for dominance begins by partitioning the total time curve into one of three general patterns or trends, namely an exponential trend, a logarithmic trend, or a linear trend. The first derivative of this variable describes the net rate of change during a given period. In Ford's procedure, one first takes the absolute value of the first derivative and then calculates the movement of this rate of change to obtain the second derivative. If the second derivative is positive in an time interval, then the shape of the curve is exponential. If the second derivative is negative, the shape of the curve is logarithmic. Finally, if the second derivative exactly equals zero, the one is dealing with an linear trend.

(Figure 21 at end of paper)

Using the POWERSIM language we found it extremely easy to obtain the second derivative described above. Figure 21 shows the system when Workers equals 100, Av_Wkr_Att equals 40, and the drainage process was turn on. The second derivative is plotted in 21-B. We found that in the range of time 0.0 to time 11, the second derivative was negative, indicating a logarithmic trend. From around time 11 to time 18, the second derivative turned positive, indication exponential trend. Finally from time 18 to the end of the simulation run, the second derivative turned negative again.

Thus, we have partitioned the total time curve into three intervals. The next step in Ford's procedure is to start with the first interval and systematically turn off each of the loop singally as well as in combinations to see if a given loop or set of loops affects the pattern for that interval. In this paper we are only going to report the analysis of the first interval for illustrative purposes. We first deactivated loop #1 (see Figure 20), which controls the draining process. After running the simulation with loop #1 deactivated, we found that the second derivate, between time 0.0 and 11, was negative. Since this matched the original run with Loop #1 intact, we concluded that this loop was not dominating the behavior of the system in this interval.

After activating Loop 1 again, we next deactivated Loop #2 by severing the connection between the Av_Wkr_Att and, associated with the rate variable TransferOfAtt. The second derivative again was negative during this interval, which matches the intact results. Thus, we concluded that Loop #2 was not dominating the behavior of Av_Wkr_Att during this interval.

The next candidate was Loop #3. Av_Wkr_Att is not in this loop. We deactivated the loop, ran the simulation and again found that the second derivative was always negative during this time interval.

After controlling each loop singly, we next undertook deactivating pairs of loops to look for an interaction effect. When we deactivate Loops #1 and #3, we found that the second derivative during this initial interval was always negative in value. The same was true of simultaneously deactivating Loops #2 and #3. Again the second derivative was negative, indicating that this combination of loops, acting together, did not determine the logarithmic behavior observed in the variable of interest.

(Figure 22 at end of paper)

Hitting some pay dirt. Finally, we simultaneously deactivate Loops #1 and #2 and ran the simulation again. Figure 22 shows the results of this analysis. The original behavior pattern can be seen in 22-A, while the pattern obtained by deactivation is shown in 22-B. Finally, the variable, Derv2AvAtt, the second derivative, can be seen in 22-C. This time the second derivative is positive, indicating an exponential trend over this initial interval.

We interpret this outcome as evidence that only in combination can the loops dominate the behavior of the variable of interest. They comprise a "shadow pair." Neither dominates singly. This is what we conclude from this analysis. At this moment we are in the process of applying Ford's procedure to the next two periods demarcated in Figure 21. These will be reported at the conference in August. We have found some interesting multiple loop dominance. Moreover, although initially we thought the second and third interval were unitary in what could dominate the behavior during those times, we found that we had to disaggregate both the second and third time periods into subintervals. For example, in the second period, when deactivating Loop#3, we found that its second derivative was positive from time 11.28 to 17.25, which matches the baseline during this interval, and went negative from 17.25 to time18.125. Since the baseline derivative was positive, Loop #3 became briefly dominant during this second subinterval.

In summary, we have first considered the behavior of the coflow structure in isolation. However, usually one models other processes along with the coflow structure. In this paper, we only added a draining process, but this complication lead to some surprising and interesting behavior patterns. The use of Ford's procedure for assessing the dominance of the loop structure reinforces the conclusion that the dominance relationships are indeed complex in this situation. For example, when we deactivated Loop #1, we in effect moved from the complete model to the simpler coflow situation. Yet we found that the second derivative did not change during that initial time interval. This indicated that, under those circumstances, the drainage loop was not dominant by itself.

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FOOTNOTES

[1] We want to thank Professor Hines for send us a copy of his modification of the classical coflow process

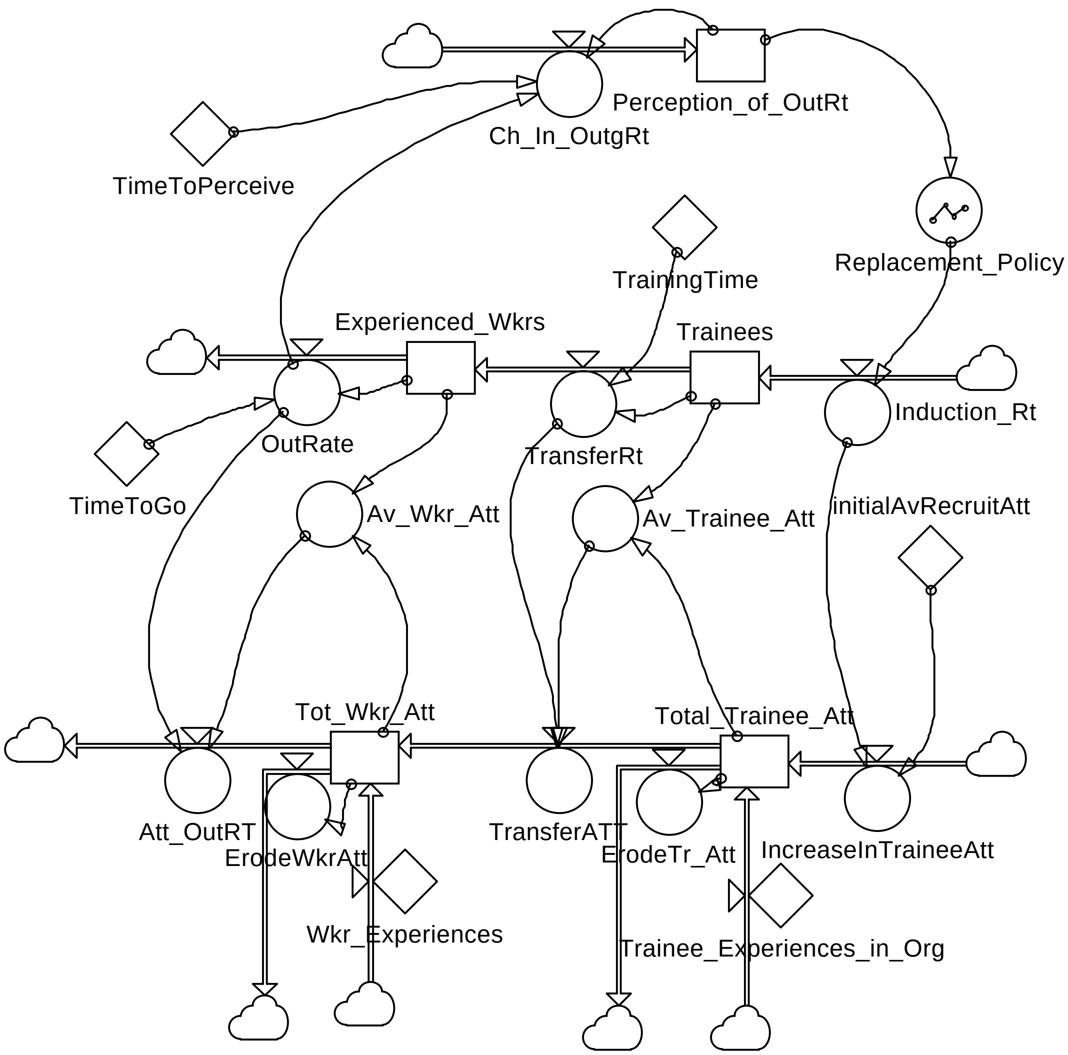


Figure 1. Typical example of how a coflow process is combined with other processes.

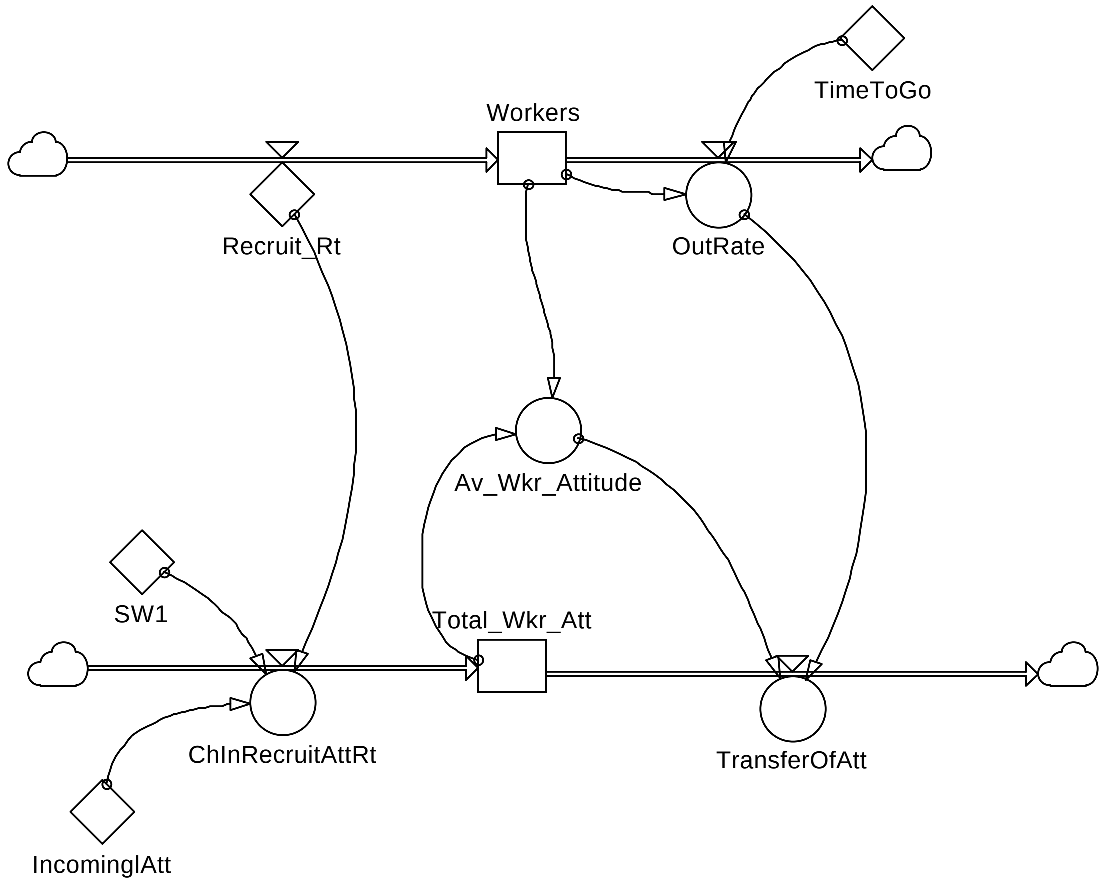


Figure 2. Simplified version of the classical coflow process.

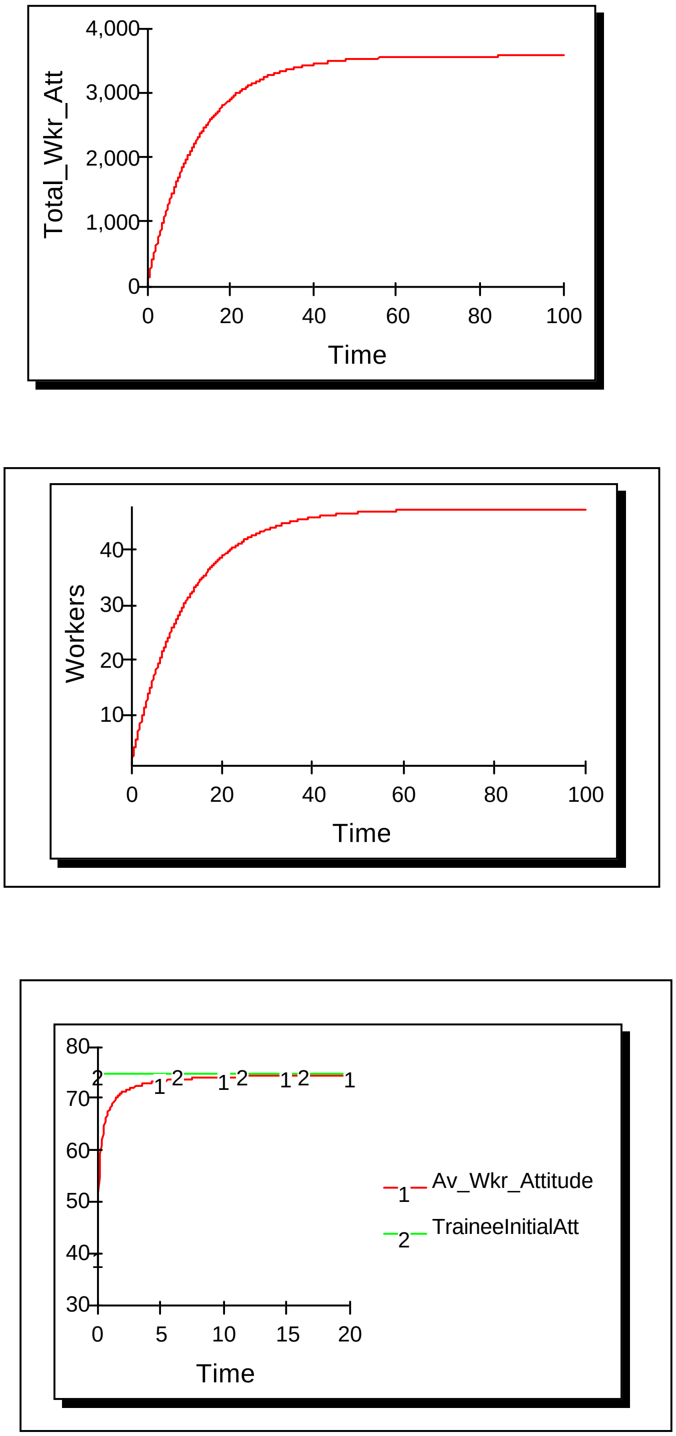


Figure 3. The basic output of the classical coflow structure.

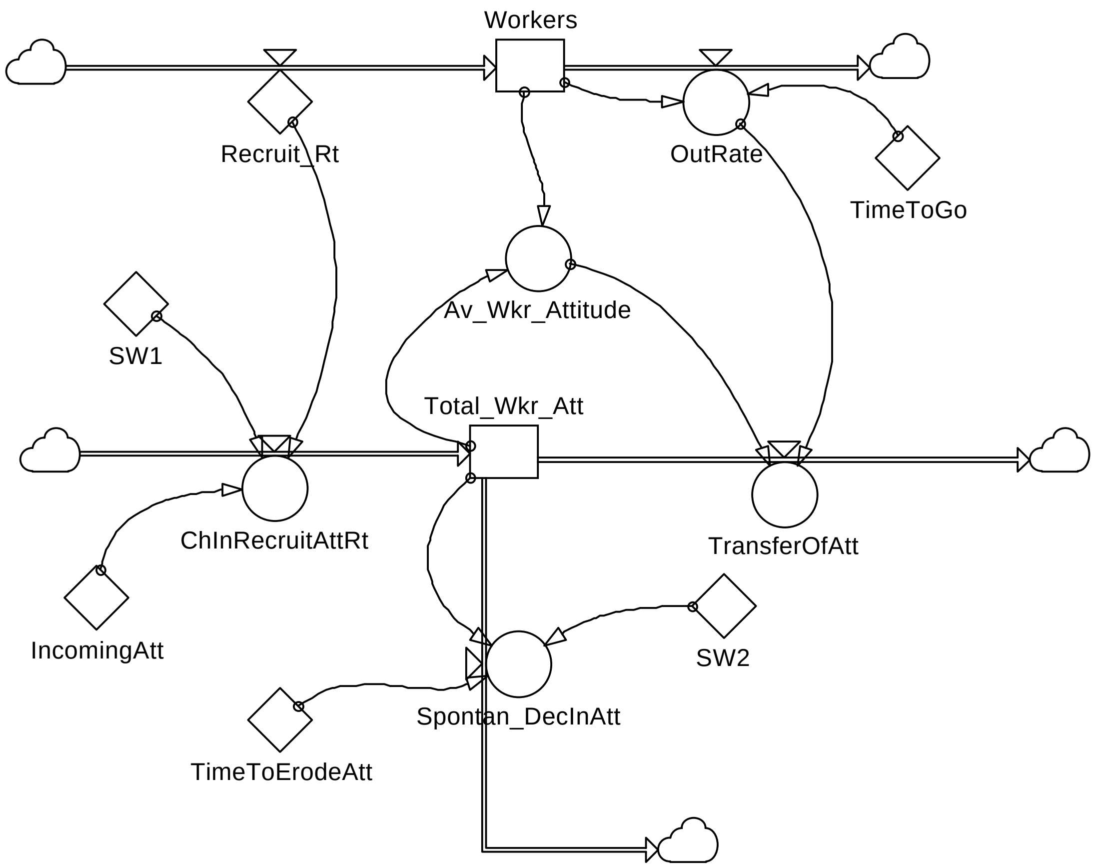


Figure 4. Simplified version of the classical coflow process and a draining process on worker attitudes.

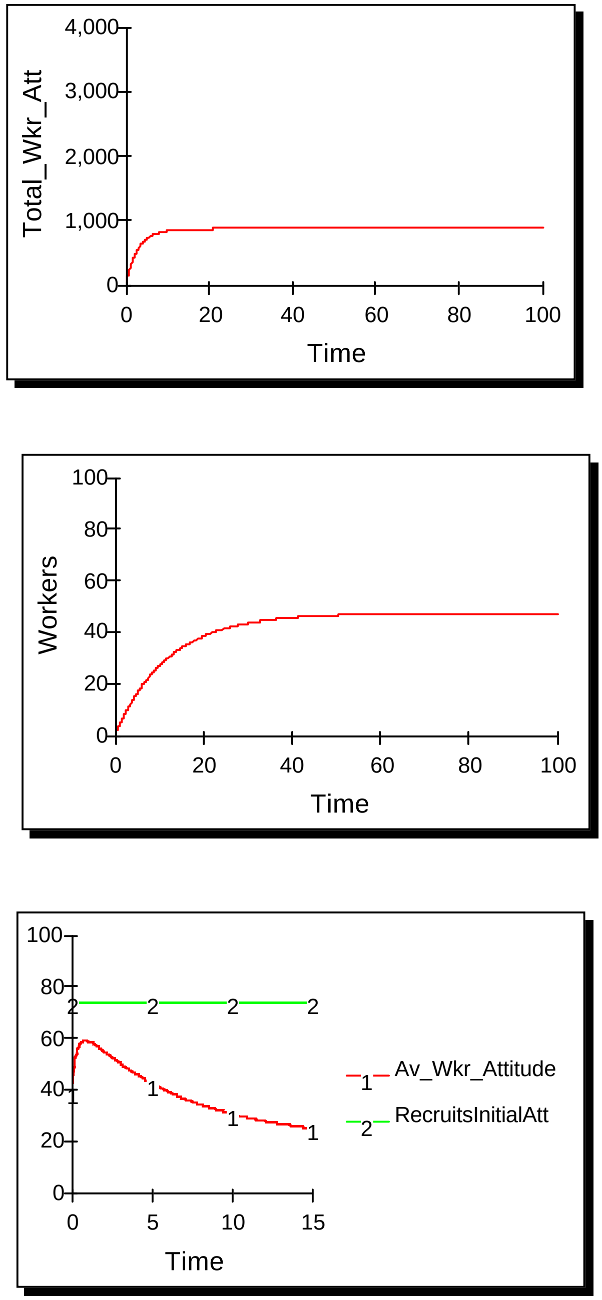


Figure 5. Average attitudes of workers when attitudes erode relatively quickly: TimeToErodeAtt = 4 months.

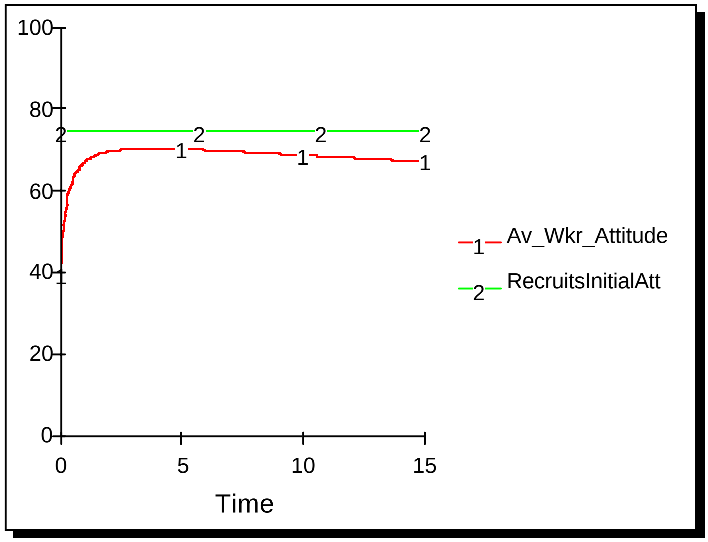
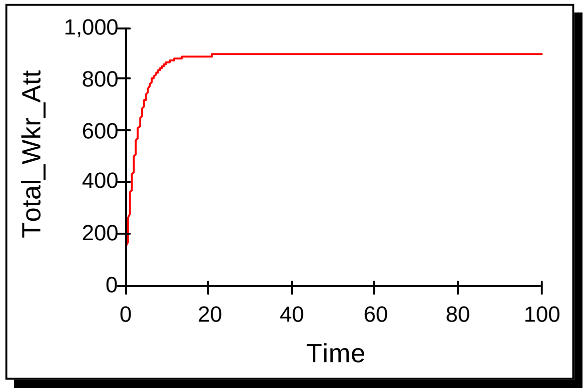


Figure 6. Av_Wkr_Att when TimeToErode_Att = 60 months.



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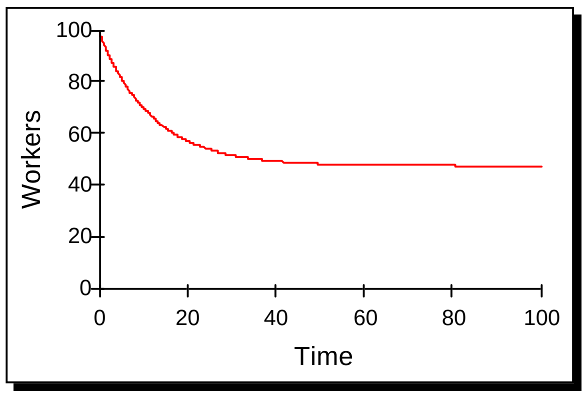

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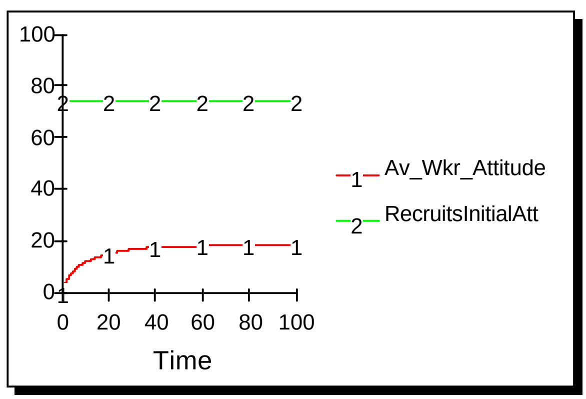

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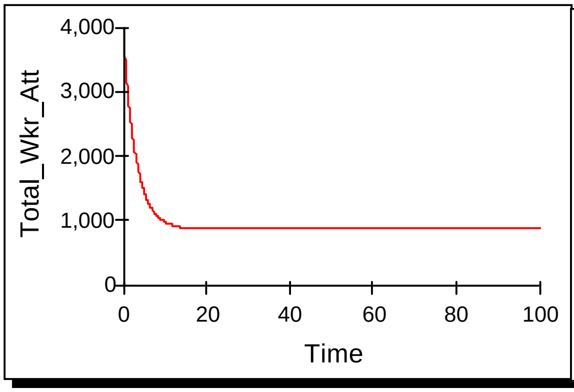
Figure 7. Attitude change when initially Workers are above equilibrium and Av_Wkr_ Att is below equilibrium.



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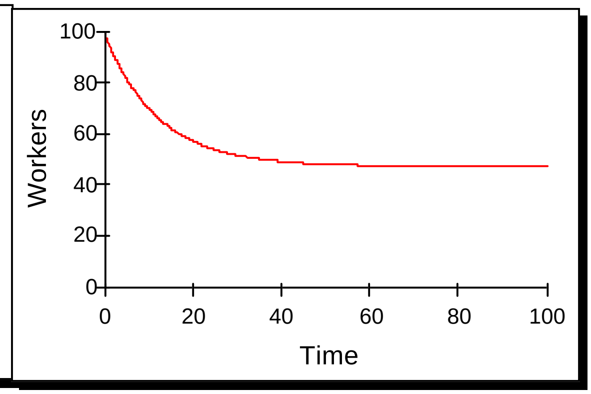

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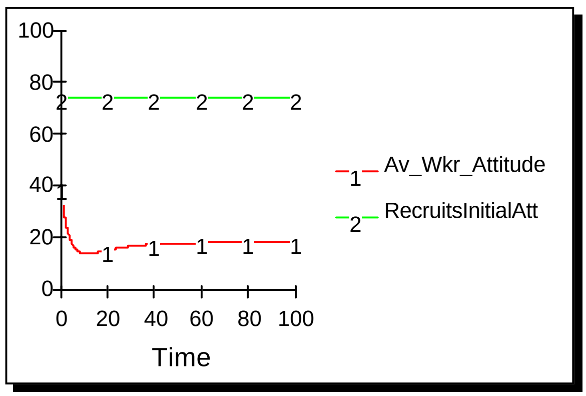

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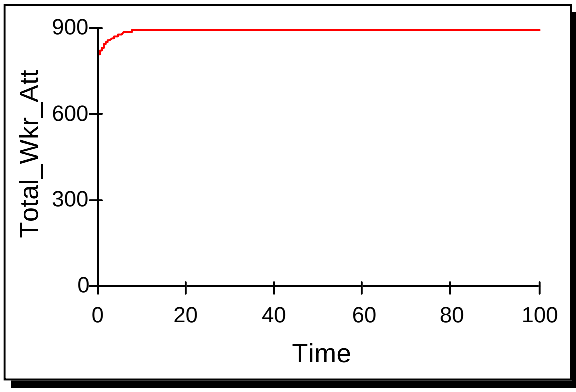
Figure 8. Results of a run where <u>both</u> initial Workers and the Av_ Wkr- Att were above their respective equilibrium points.



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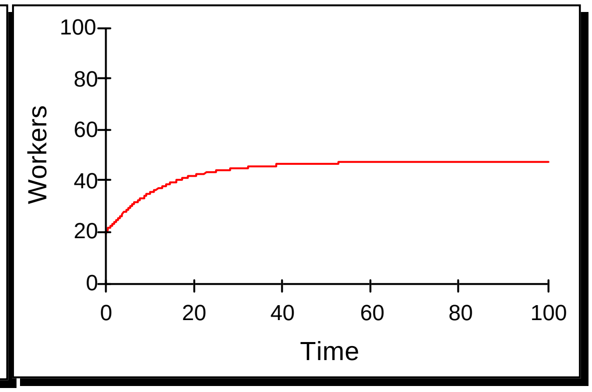

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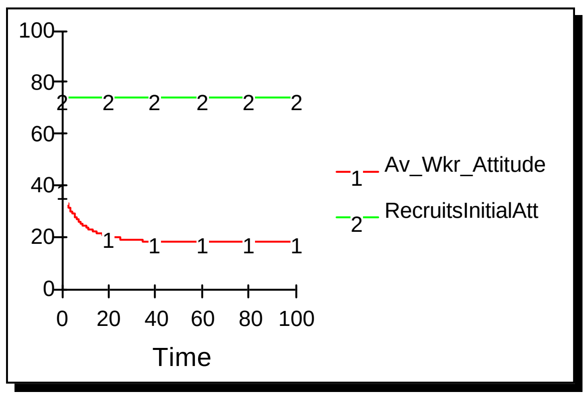

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Figure 9. Simulation run where initial Workers are below their asymptote and Av_Wkr_Att is above its Asymptote.

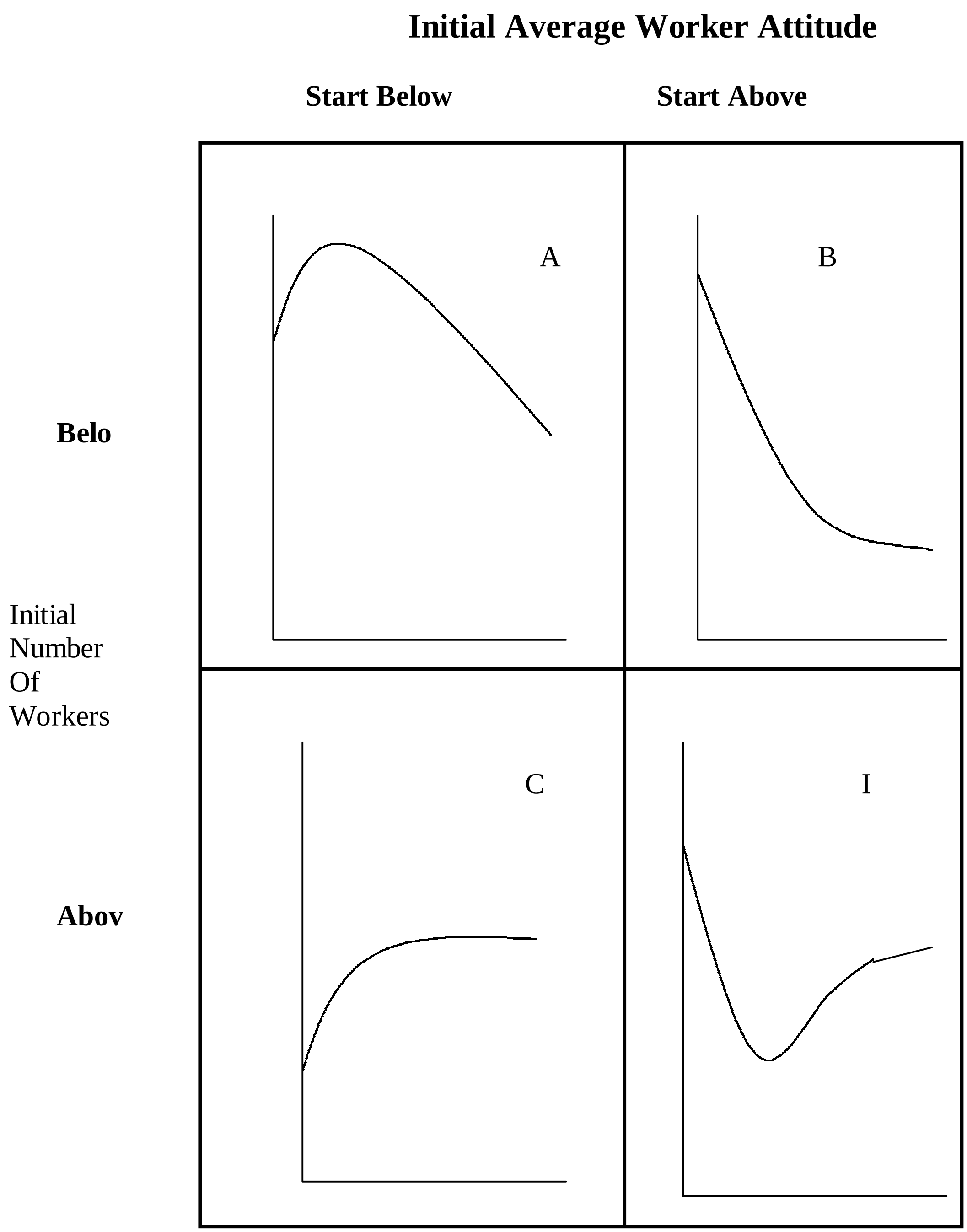
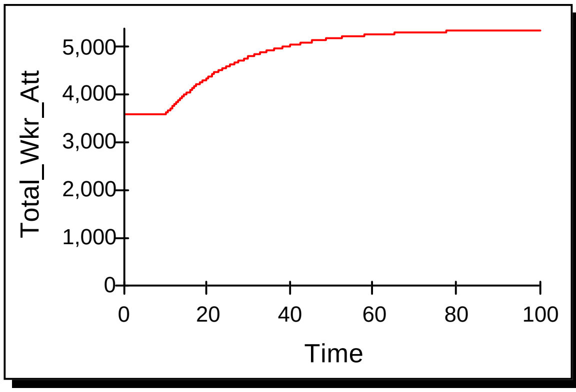


Figure 10. Patterns of average worker attitudes as a function of initially being below or above maximums or minimums.

Draining Process Is Off



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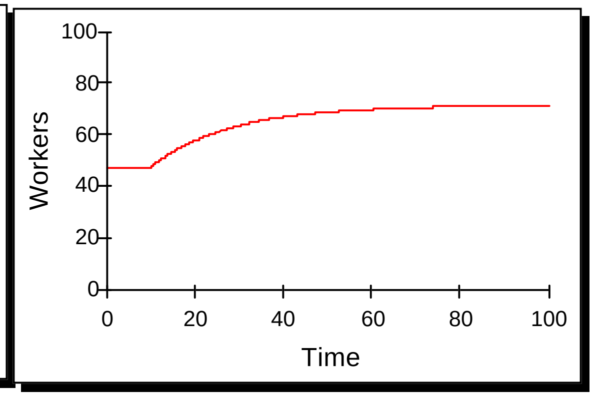

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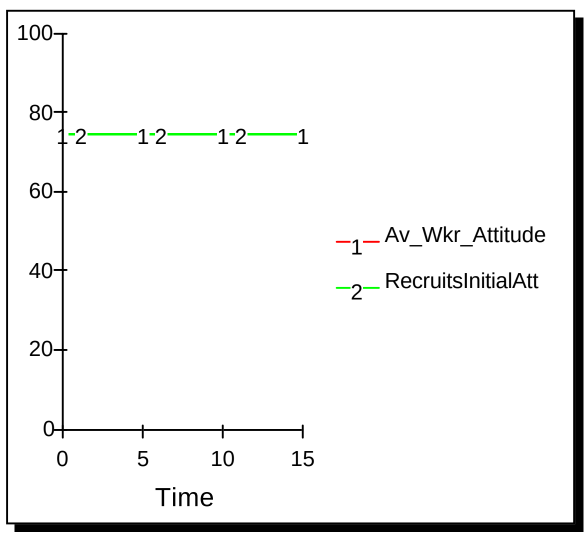

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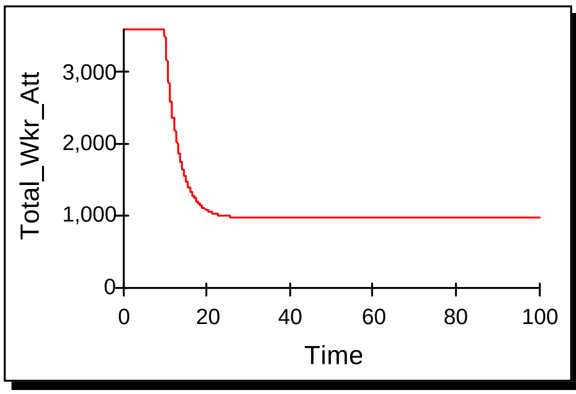
Figure 11. Equilibrium run for the classical coflow process when the constant for the material delay, Workers, was increased.

Draining Process Turned On At Time 10



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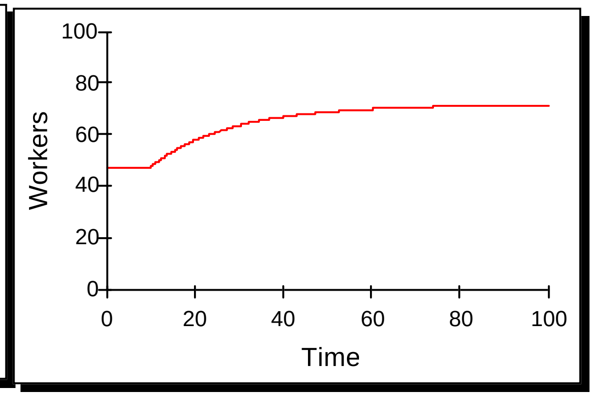

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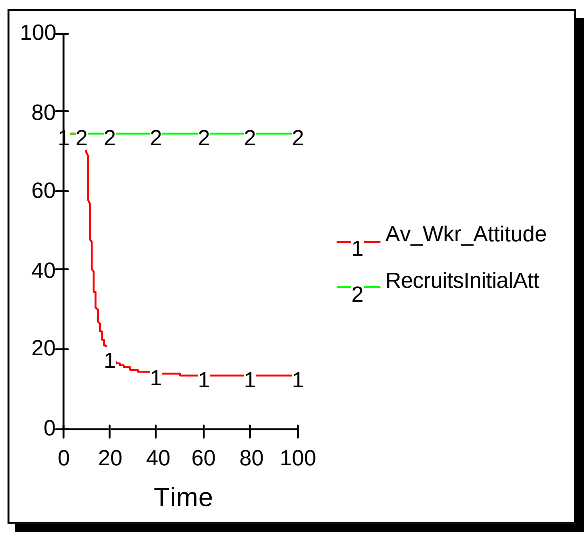

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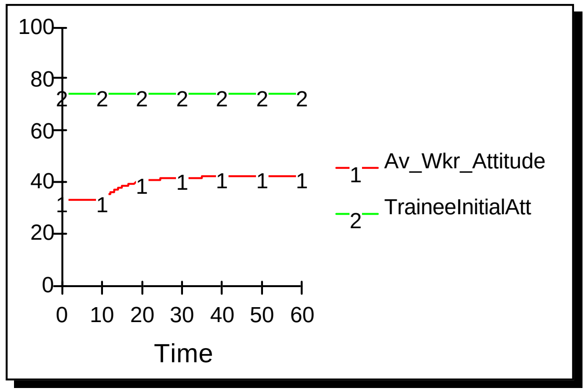
Figure 12. Equilibrium run for the combined coflow and draining structures when the constant for the material delay, Workers, was increased at time 10.



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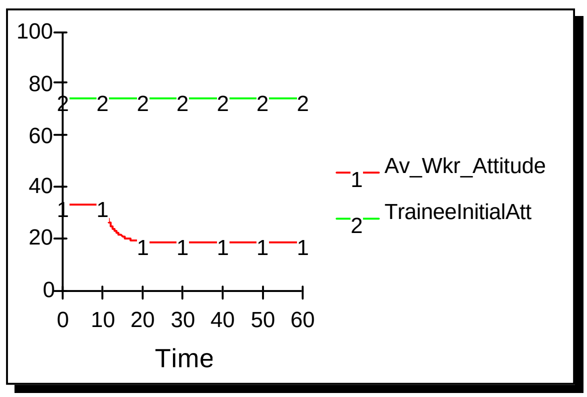


B

Figure 13. Equilibrium run for the combined coflow and draining structures when TimeToErode_Att is moved up or down by six

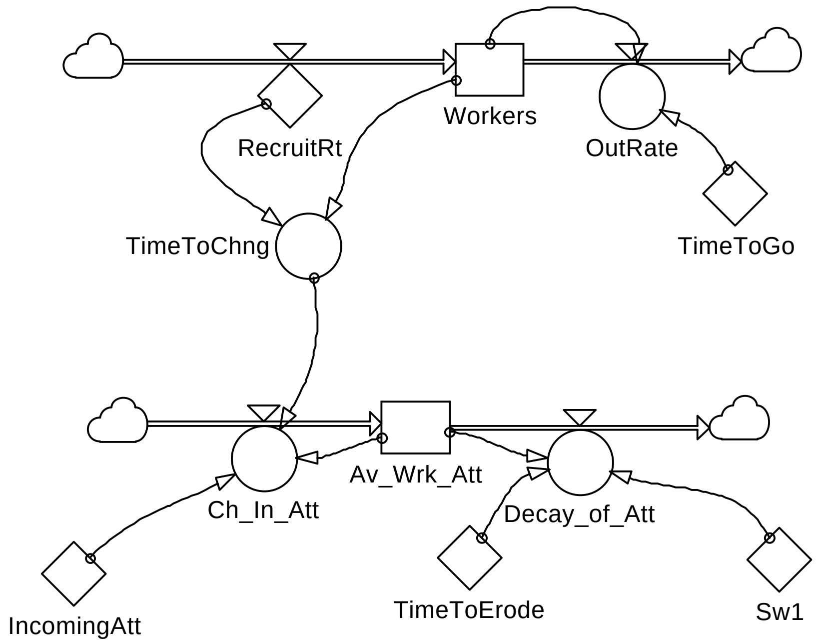
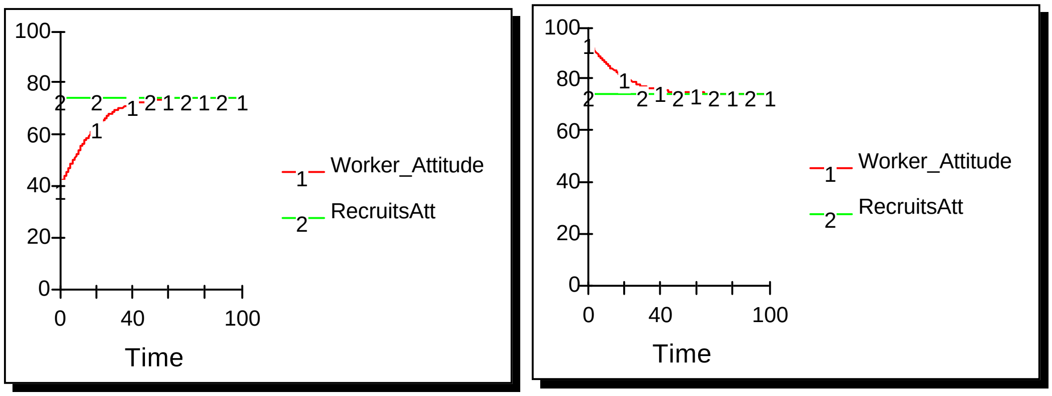


Figure 14. The Hines coflow model, where Av-Wrk_Att is treated as a stock variable.

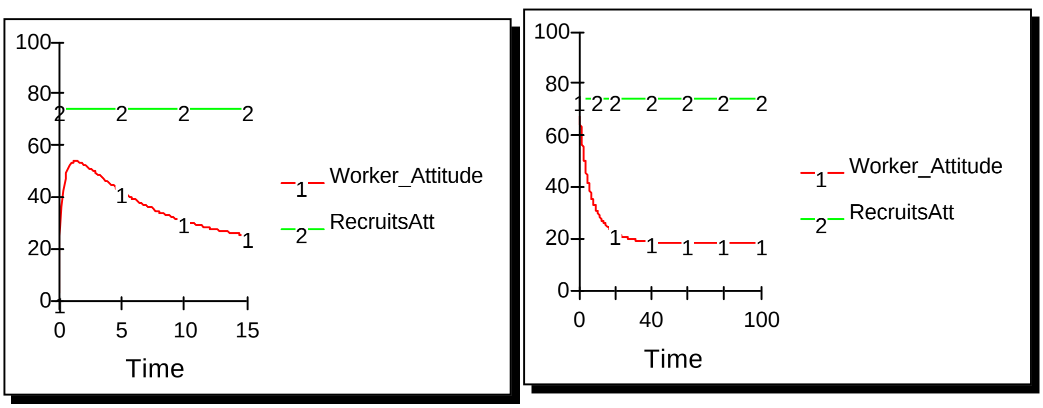


A B

Hines Coflow Process Alone

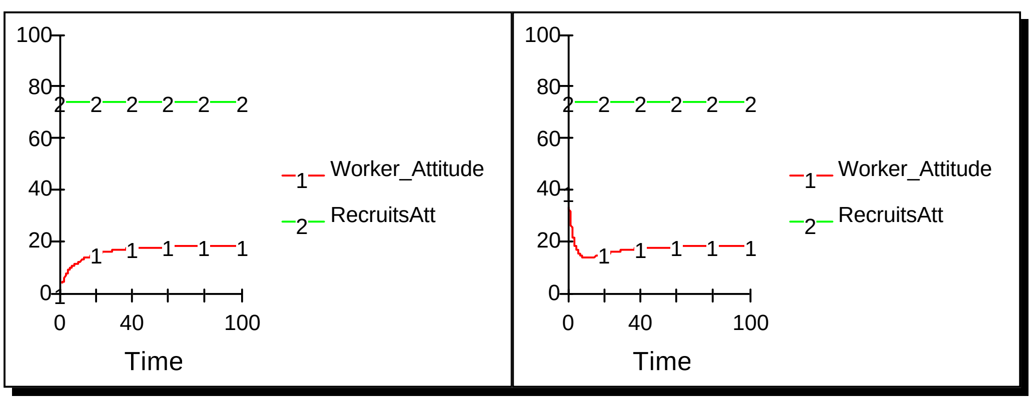
Below **Above**

Below



C D

Above



E F

Hines Coflow With A Draining Process On Attitudes

Figure 15. Results of runs with and without draining

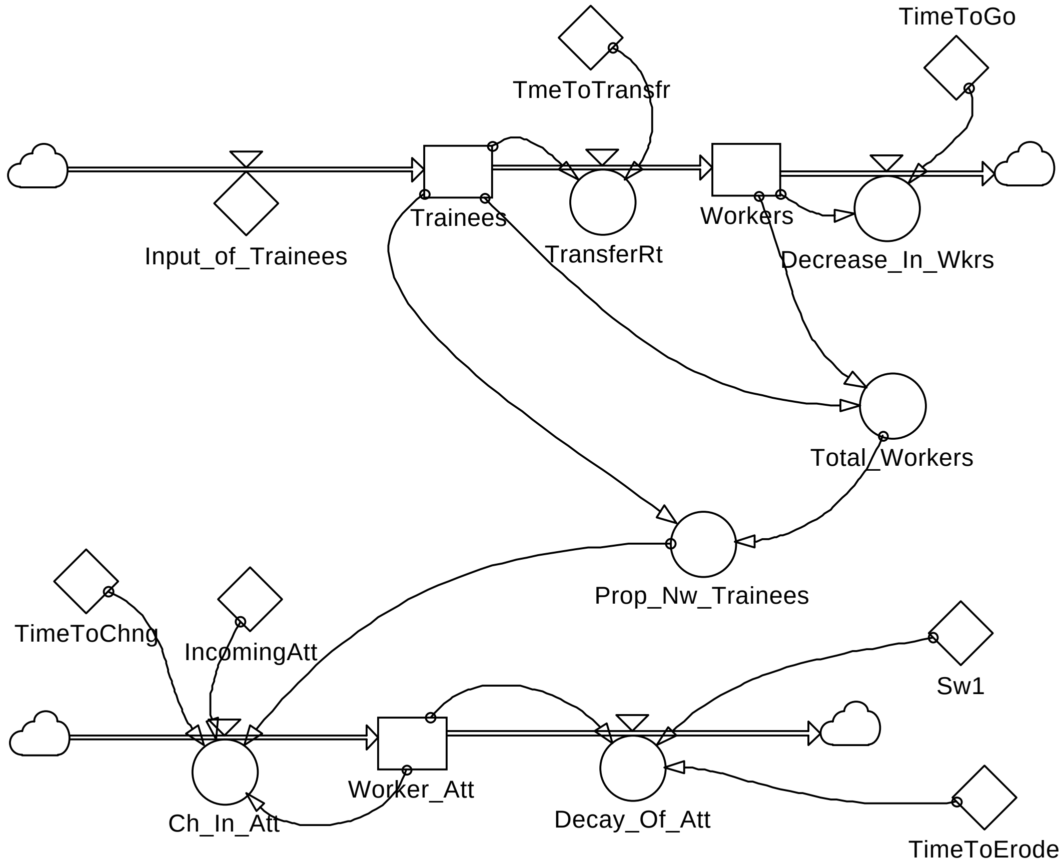


Figure 16. Disaggregated model. Alternative formulation of the classical coflow process, where the influence of new people on worker attitudes is proportional to their relative number of recruits.

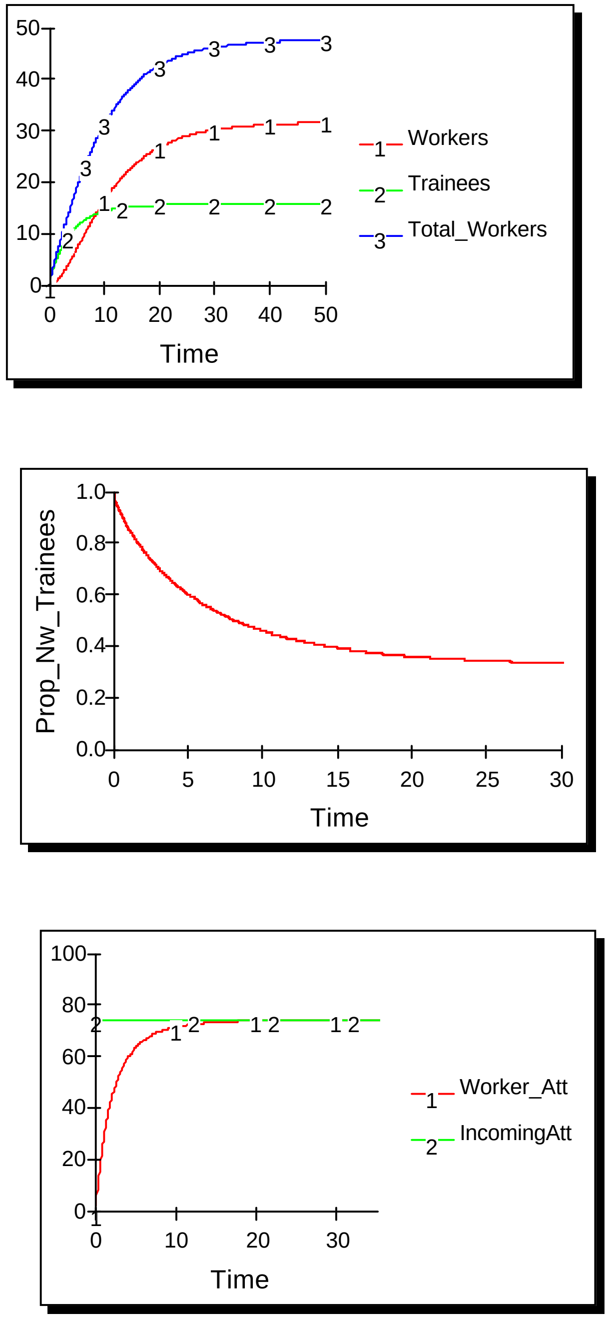


Figure 17. Baseline run for a disaggregated coflow model with no draining process active.

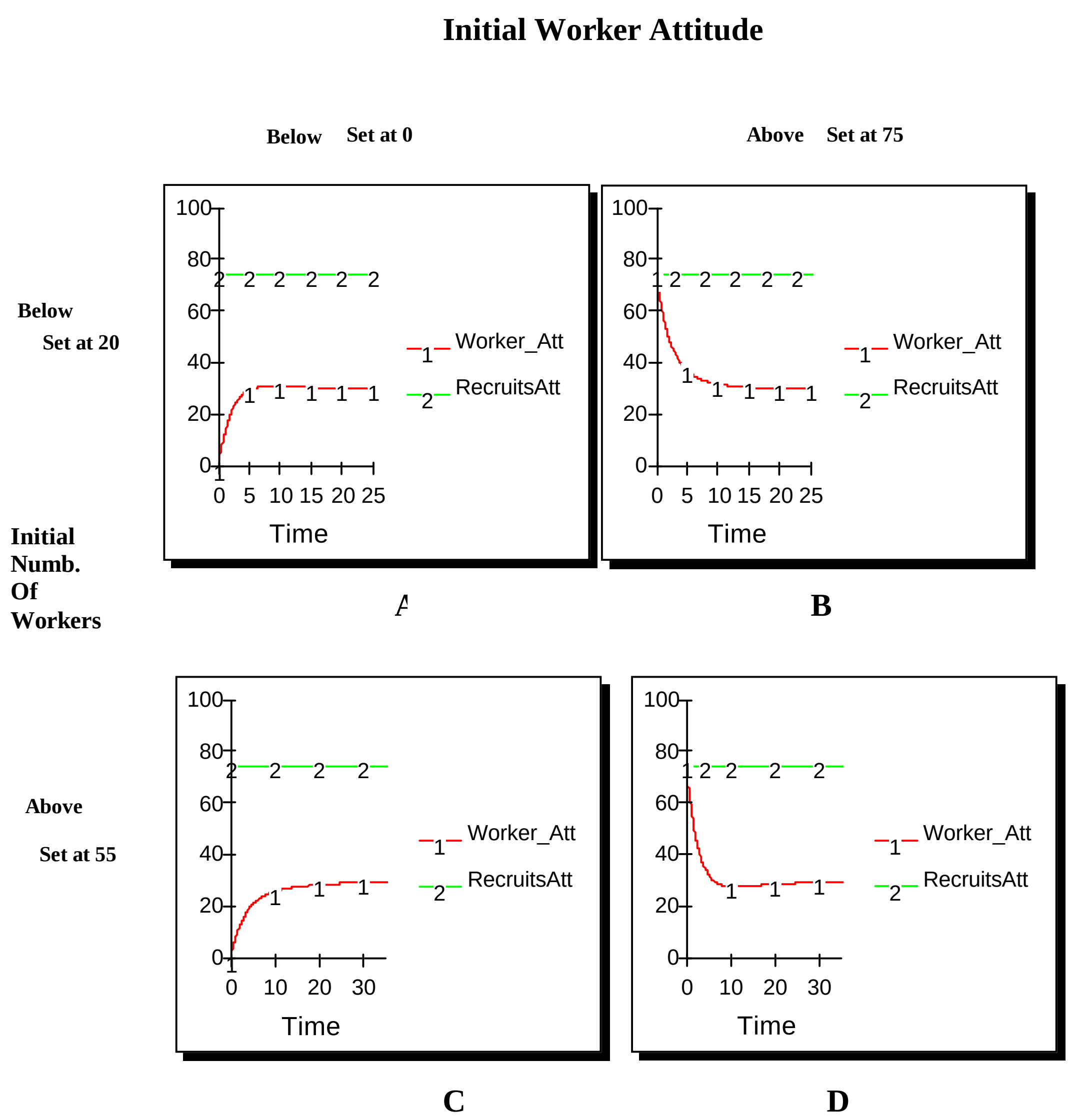


Figure 18. The aggregated model output, when Trainees are set at equilibrium and Workers and Worker Attitudes are set either above or below maximum or minimum

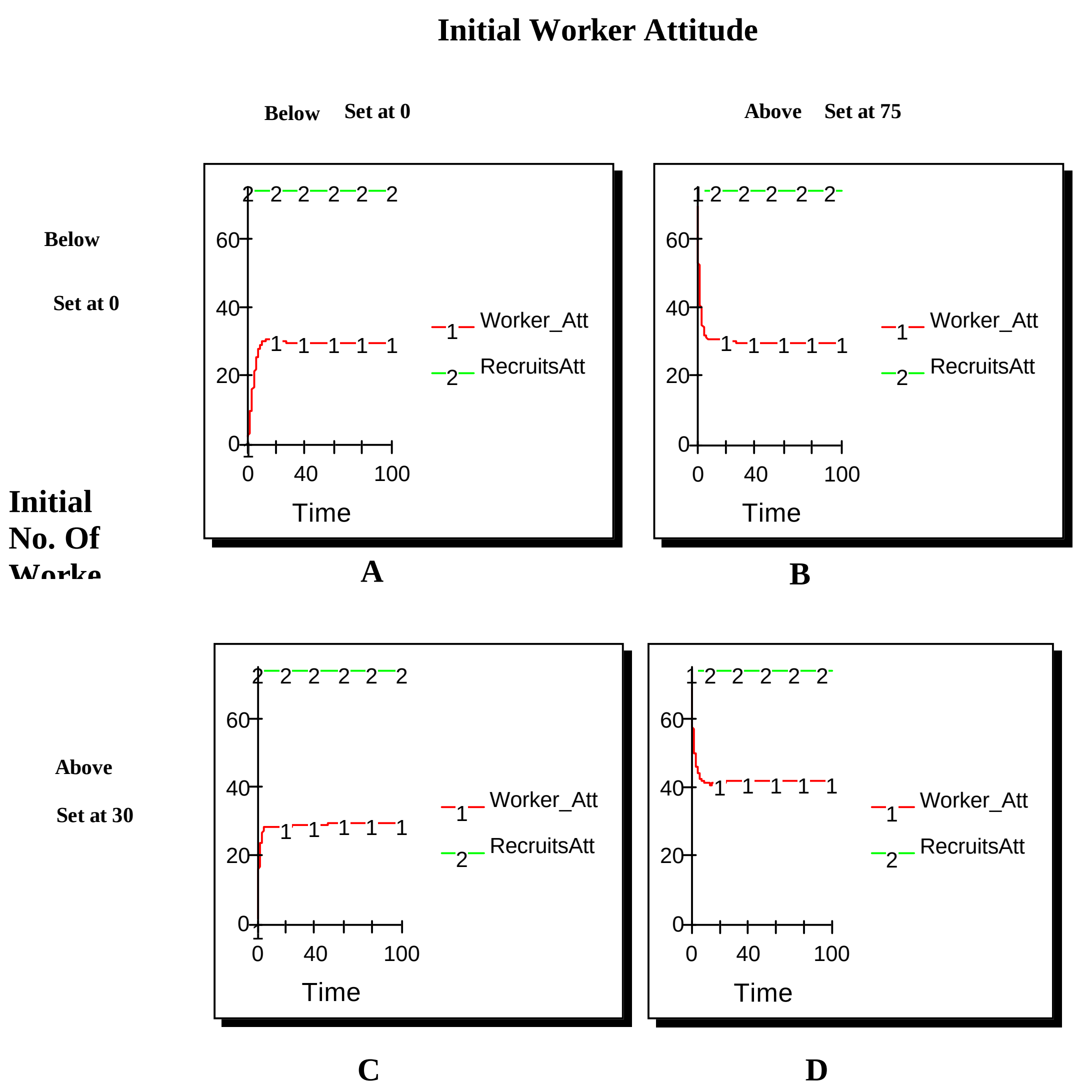


Figure 19. The aggregated model output, when Workers are set at equilibrium and Trainees and Worker Attitudes Set either above or below maximum or minimum.

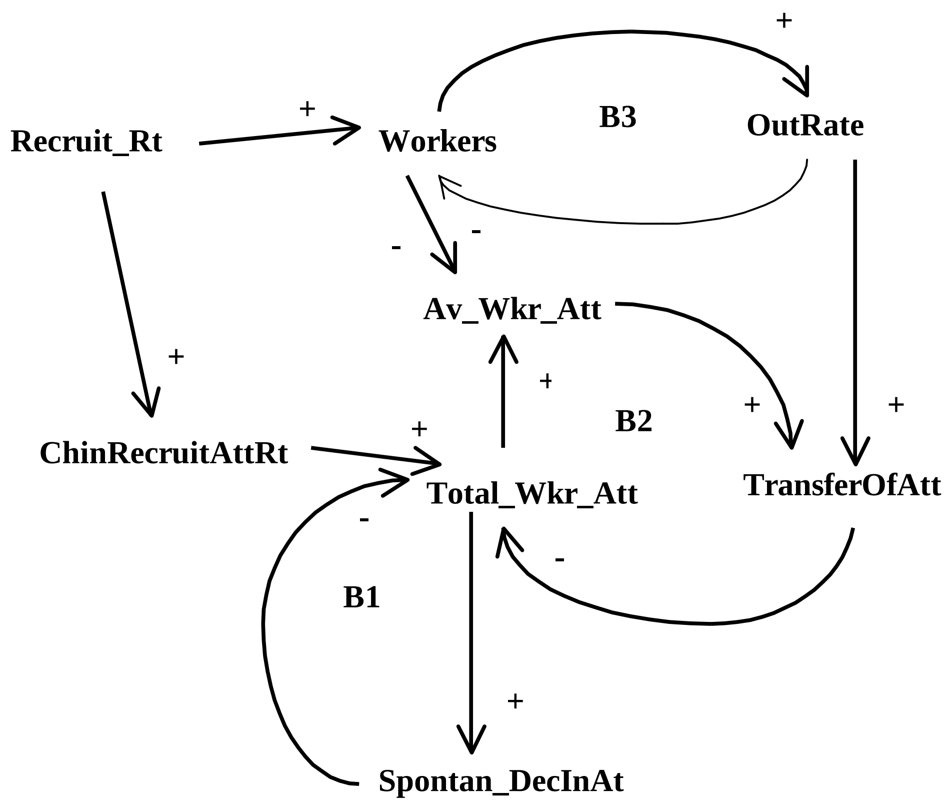
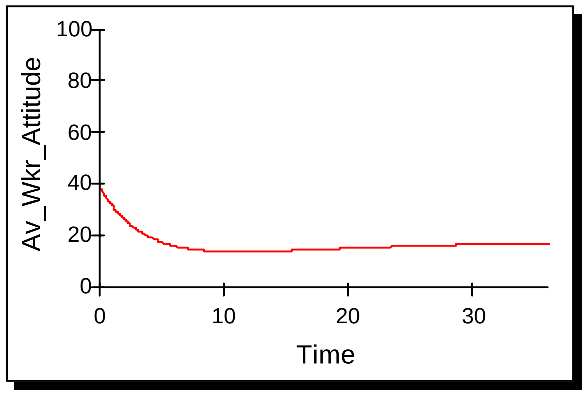


Figure 20. Causal loop representation of the classical coflow structure, combined with a draining process.



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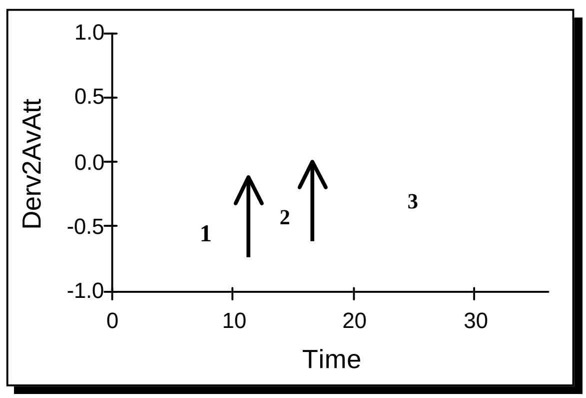
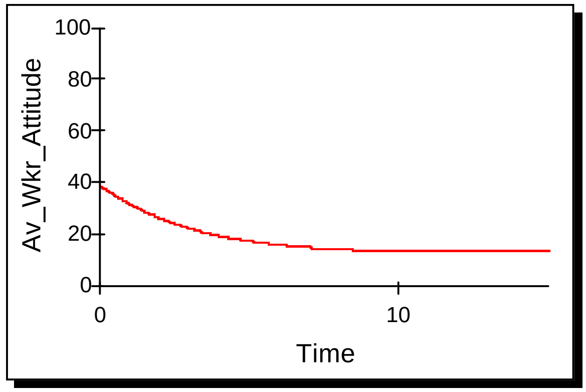


B

Figure 21. Partition of the total time curve into intervals containing either an exponential, logarithmic, or linear trend according to the second derivative.



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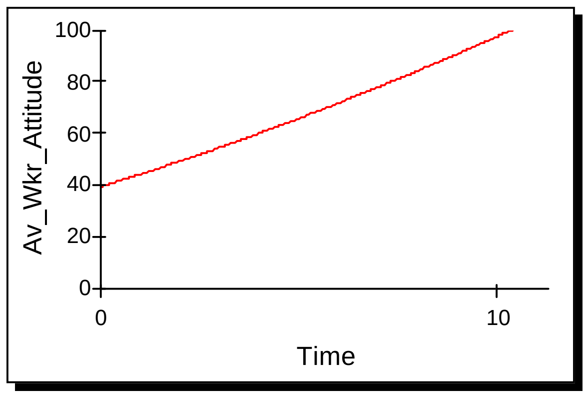

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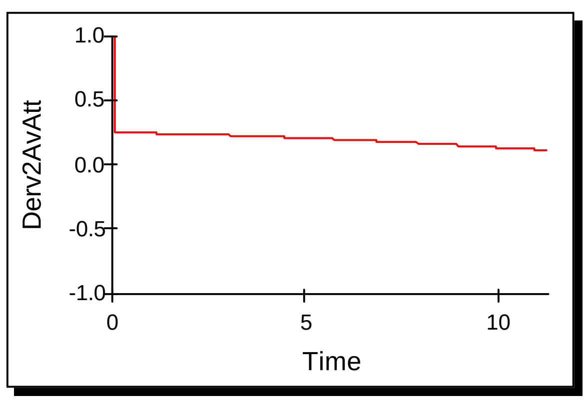

C

Figure 22. The response of the system when a combination of Loop #1 and #2 are simultaneously deactivated.