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SYSTEM DYNAMICS MODELLING IN TEACHING ECONOMICS

Lending grows in popularity among both young and older people. Simple system dynamics model can be useful for the illustration of the loan growth with interest accrual and possibilities to repay it. The paper will present model of loan that has to be repaid under different conditions. The loan is stock and repayments is outflow from this stock. Let the initial loan amount be 1 000 USD. It is possible to try the simple repayment scheme: repay this loan with equal payments of 100 USD each month. In this case, the debt will be repaid in 10 month. This logical expected behavior and structure that produces this behavior are shown on the graph below (Figure 1).

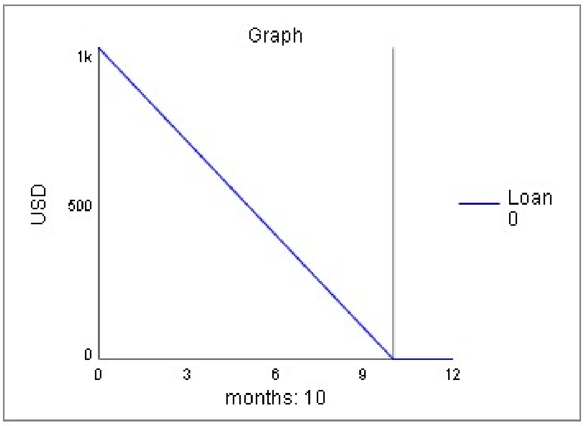

Figure 1. **Equal repayments example**

In this example, the time to repay debt was specified according to the monthly repayments. However, it is also possible to define the time first. One obvious way is to state the time and calculate monthly payments. For example, if one would like debt to be repaid in 4 month the month repayment should be: 1 000/4 = 250 USD/month. So one observes the full repayment at time 4.

Introduced mathematical calculations are clear, but they are done separately not within the model by internally inbuilt structure, which is not appropriate approach for system dynamics. That is why the special structure to show the stock adjustment to the desire level within stated time to be presented further. In order to do this it is necessary to add converter with adjustment time. Let adjustment time be 4 month. Important information for this structure is the desired level of loan. To fully repay it desired level have to be 0 USD. The repayments depend on current level of loan, desired level of loan, and loan adjustment time:

$$Repayments = (Loan - Desired\_loan) / Loan\_adjustment\_time$$

Now it is time to test the structure to understand whether it produces the exact expected behavior (Figure 2).

Here the first interesting result can be noticed. The loan still exists in time 12 despite the fact that adjustment time was 4 month. To understand why this happens it is important to look precisely at the equation of repayments. This equation states that repayments at each time will be 1/4th of the difference between current loan level and 0. At time 0 it will be: (1000-0)/4 = 250 USD/month. Therefore at time 1 the loan will be 1 000 – 250 = 750 USD. With decline of loan, the next repayment also decreases. It will be 750/4 = 187.5 USD/month. The loan at time 2 will be 750 – 187.5 = 562.5 USD. It is possible either to continue calculations or see with the use of graph that at time 3 the loan will be 461 USD and at time 4 – 356 USD. The conclusion than can be made with these calculations is that this structure decreases the loan each time with slower pace.

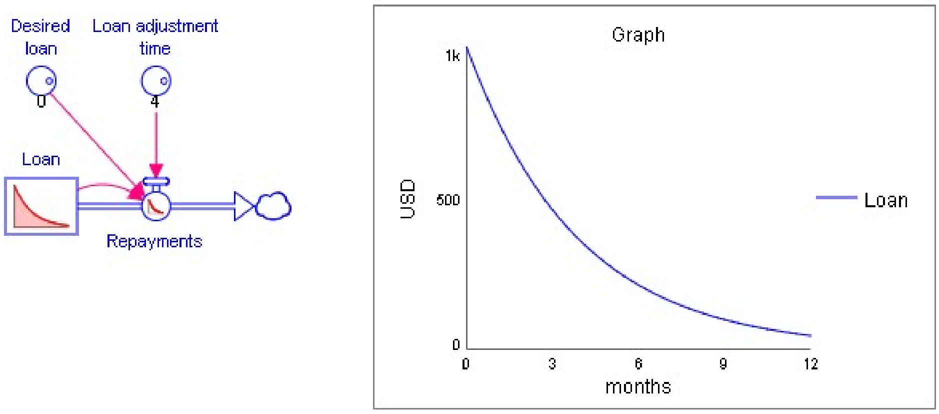

Figure 2. **Example with adjustment time**

In order to understand this process so-called “causal-loop diagram” (CLD) will be used (Figure 3). In this model, there are two variables: “Loan” and “Repayments”. It is obvious that if outflow “Repayments” is connecter to the stock “Loan” it makes impact on it. Moreover, this flow decreases the stock, repayments decrease the loan. Therefore, sign ‘-’ is placed near the arrow: the bigger is repayment the lower loan becomes. It is also obvious from equation that loan influences repayments. Moreover, according to the equation inside the “Repayments” outflow the lower is “Loan” the less “Repayments” becomes. Therefore, there is also connection, which is on the contrary positive.

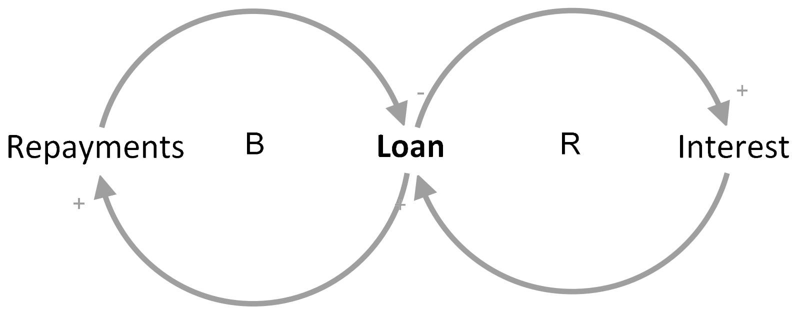

Figure 3. **Causal-loop diagram**

In system dynamics, this type of relations when variables influence each other is called ‘**loop**’. If increase in one variable produces decrease in another and feedback to the first one is negative then this type of loop is called '**balancing loop' (counteracting loop)**. This balancing loop produces behavior that we have seen just above with loan repayment – exponential decay. The decay can be negative which means that stock decrease with slowing pace to the desired level. It can also be positive, which means stock increase with slowing pace to the desired level.

Still it is not clear how to reach the desired output – make loan 0 at time 4. In this paper, the details will be omitted, but as the amount of repayments decrease with decrease in loan, adjustment time should be smaller than 4 months. It is possible to use "Stella Live" and change adjustment time to see the necessary time to cover debt in time 4. After some experiments, it is possible to see that loan becomes close to 0 if adjustment time comes close to 1. To make a simple rule for this peculiarity of system dynamics models it is necessary to remember that in average 3.5 adjustment time are needed to reach goal. Therefore, for loan to be 0 at time 4 the adjustment time should be close to 4/3.5 ≈ 1.14 month.

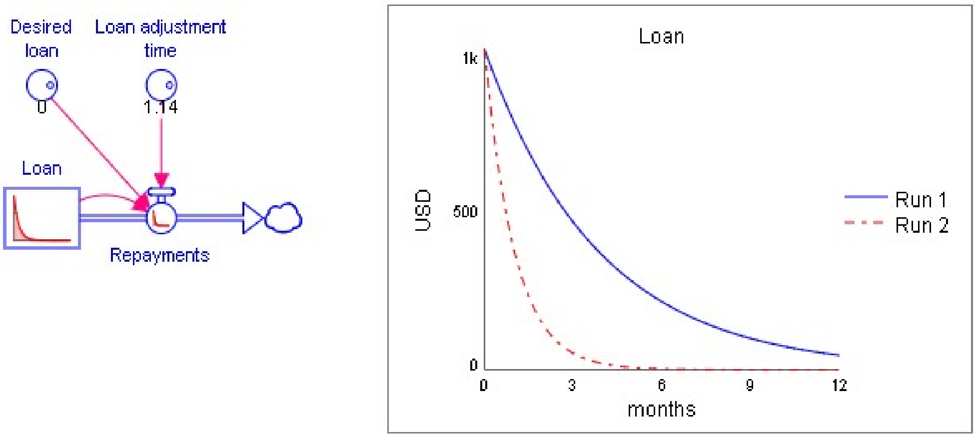

Figure 4. **Example with targeted adjustment time**

In this simple example, the complicity of the balancing process representation for the purpose of repayment during the stated time is challenging comparing to the simple mathematical calculations. However, it becomes much more obvious in complex cases.

Previous simple structure represents the situation when some amount of money was borrowed once and repayment takes place during some time. However, in majority of cases the loan includes interests. It means that money borrowed is given under condition of some additional payments, which indicate the price of this loan. Usually these payments are defined in the form of some fraction from the current loan. This fraction is called interest rate. The formulas for the new model elements are the following:

$$Interest = Interest\_rate * Loan$$
$$Interest\_rate = 0.20 \text{ (units – per month)}$$

If increase in one variable produces increase in another and feedback to the first one is also positive then this type of loop is called '**reinforcing loop'** (Figure 3). Whatever small increase will occur for example in interest it will be reflected as increase in loan and further growth in interest and so on. This structure will increase the amount of loan each month. For this case, it will be more complicated to calculate the amount of monthly repayments without model and special structure to repay the loan at time 4. For example, if the initial loan is 1 000 USD, previously it was enough to pay 250 USD each period to repay it in 4 periods. If the interest is accrued each month in the amount of 20% the loan decreases with slow pace and becomes 0 only at time 8.25, which is more than twice longer than it was expected (Run 1 in Figure 5).

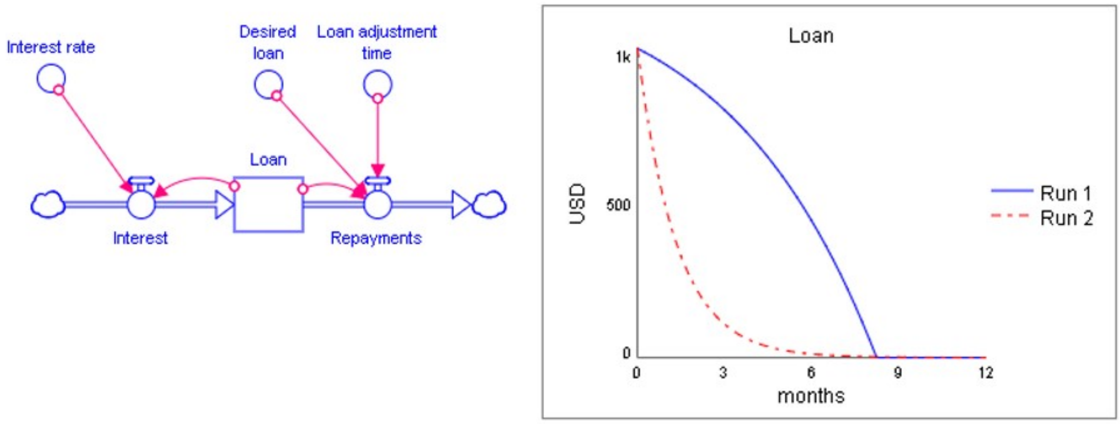

Figure 5. **Example with interest targeted adjustment time**

It is possible to understand the problem with this loan. In first month the repayments are 250 USD, but the interest is 0.2*1 000 = 200 USD. Hence, on the contrary to expected decline of the loan to 750 USD it becomes 950 USD. In such a condition, it can be rather complicated to calculate the amount of payment to cover loan at time 4. Nevertheless, the model structure makes it much simpler (Run 2 in Figure 5).

What exactly happens to loan that can be shown with causal-loop diagram (Figure 3). For this case the two loops reinforcing and balancing influence “Loan”. The first one with repayments decreases its amount, while second one increases it with interest. If two different effects that influence one element combined in one model, the more complex behavior is produced. Despite the loan growth with some pace due to interests, the balancing loop counteracts it so that adjust the loan to the zero level at time 4. So the shown structure with balancing loop is dedicated to adjust the amount of stock to the desired level no matter how many other inflows and outflows influence this stock.

Good way to understand the benefits of the illustrated adjustment structure is to see how it works under different scenarios. If inflow and reinforcing loop is stronger (makes more impact on stock), then the loan will exponentially increase. And if outflow and balancing loop is stronger, the loan will show the exponential decay decrease. To understand the features of these changes it is necessary to decompose them by driving conditions.

First important driving condition for such type of systems is the sign of the difference between inflow and outflow (net flow). If net flow is positive, then stock will increase, and if this difference is negative, then on the contrary the stock will decrease. In case inflow and outflow are parts of the different types' loops the difference will be reflected not only in sign of the change but also in the type of the behavior.

In this regard each change in parameters that will change the balance between flows will lead to major change in loan behavior. The balance condition is:

Interest = Repayments

*Interest_rate * Loan = (Loan - Desired_loan) / Loan_adjustment_time*

Hence if *Interest_rate * Loan > (Loan - Desired_loan) / Loan_adjustment_time*, the loan will grow. If *Interest_rate * Loan < (Loan - Desired_loan) / Loan_adjustment_time*, the loan will decrease.

The change in adjustment time can cause the loan to grow under all other constant conditions. If interest rate is 20 % or 0.2, the left side is 200 USD per month. And (*Loan - Desired_loan*) is 1 000 USD. So if the adjustment time is less than 5 the loan will decrease. If it is more than 5 then it will increase. And if adjustment time is 5 then the inflow will be equal to outflow and the loan will be constant. And now it is possible to show that if the initial interest rate on loan is higher than 88 % (calculations are simple, this rate correspond to the (1000 – 1000)/1.14) the loan will grow, while if it is lower than 88 % the loan will decrease. If the interest rate is 88 % then the loan is constant.

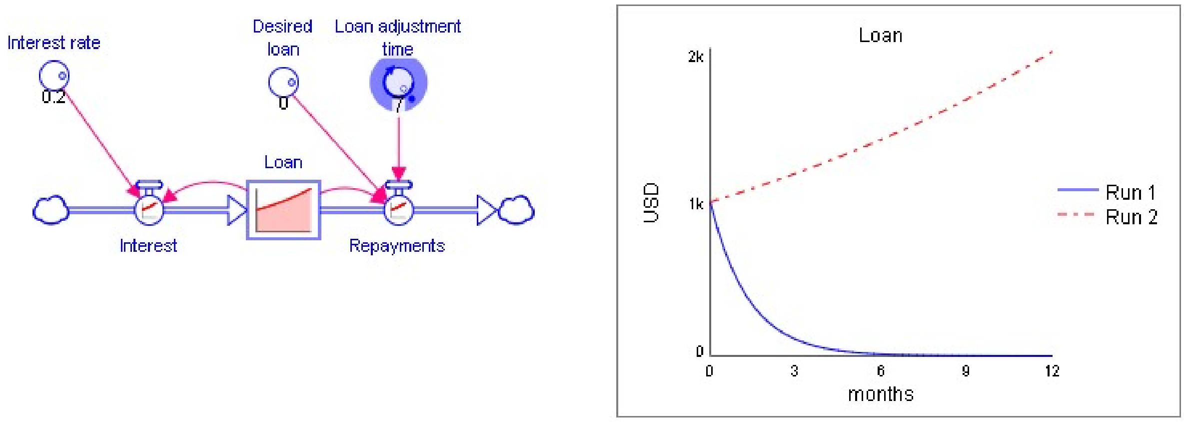

Figure 6. **Model behavior under different parameters values**

It is also necessary to remember that the final level of the loan is stated with desired loan converter. However, each period not only repayment will take place, but at the same time, significant amount of interest will be added to the debt. That is why the loan can adjust to the desired level rather slowly because of regular interest additions and will not always be able to reach desired level at all.

This problem is called delay. When model tries to repay the loan it takes into account only the amount of current loan. While the interest that accrued this period are not accounted for. This lead to the result that loan is constantly on the higher level than the desired one. The possible way to overcome this problem is to add into the model information about the interest of the period to the amount of repayments. The formula in this case will be:

Repayments = (Loan - Desired_loan) / Loan_adjustment_time + Interest

The modeling results for desired level USD before (Run 1) and after (Run these changes are shown in Figure 7. In this case the full information about the amount of current loan and interest will be included into calculation of repayments and the desired level of loan will be reached.

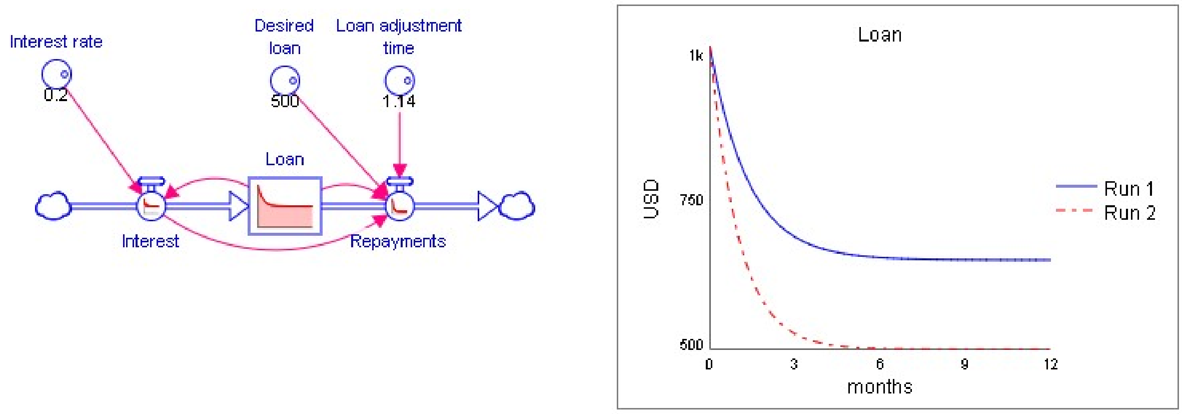

Figure 7. **Model behavior before (Run 1) and after (Run 2) delay is accounted for**

The presented in chapter model allows for the testing of the different loan parameters impact on the repayment process. It shows how the desired level, amount of interest, and desired time to repay changes the conditions of the loan repayment. All of the mentioned parameters have to be kept in mind while operating money in order to sustain the personal finances on the efficient level. The model can be used for teaching to explain: what determines the existence of loop in system; what behavior the feedback balancing loop produces; what changes if the reinforcing loop makes stronger impact on the core stock than balancing and vice versa; what parameters influence the speed and pace of the loan repayment; what are the possible ways to calculate the desired monthly repayments in order to reach the desired loan in stated time; and what are the benefits of the system dynamics approach to loan repayments calculation.

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