Link 14.2 Building a Simulation Model

Modelling Systems Dynamics

Using Vensim PLE

Workbook:

Developing an Initial Simulation Model

This workbook provides instructions to develop a model that simulates a bank account. Salary and interest payment go into the bank account and expenses are withdrawn from the account. The model introduces the notation of systems modelling using VENSIM PLE. The software is free to use for academic purposes and can be downloaded from: http://vensim.com

1. Start a New Model

1.1 **From the FILE Menu, Select NEW MODEL**

A dialog box will be displayed.

1.2 INITIAL TIME is the starting point for the simulation to run.

Set the INITIAL TIME as 0

1.3 FINAL TIME is the end point for the simulation to stop.

Set the FINAL TIME as 12

1.4 TIME STEP is the incremental time periods in the simulation.

Set the TIME STEP as 1

1.5 UNITS for TIME is the time descriptor for the simulation.

Set the UNITS FOR TIME as MONTH

Press OK.

This means that the model will simulate a series of events from 0 to 12 months.

2. Save the New Model

2.1 **From the FILE Menu, Select SAVE AS**

Type the file name 'initial model'.

Click on SAVE button.

1. Start a New Model

3. Add a STOCK

3.1   **From the TOOL BAR, Select the *Box Variable Level Icon*** (This looks like a box with the letters VAR and a pencil).

       Click on the icon once.

3.2   **Move the cursor to the centre of the screen and click once.**

3.3   **Type the text 'BANK ACCOUNT' and press ENTER.**

3.4   **Click on the circle at the bottom right hand corner of the box and holding the mouse button down, drag the circle in the bottom right hand corner of the box to change the size of the box.**

       A box with the word 'BANK ACCOUNT' should now be in the centre of the screen.

This represents the STOCK of money that is your bank account.

4. Add an INFLOW

4.1   **From the TOOL BAR, Select the *Rate Icon*** (This looks like an egg timer with an arrow running through it).

Click on the icon once.

4.2   **Move the cursor anywhere to the left of the BANK ACCOUNT and click once.**
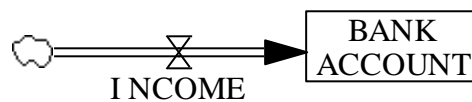
This will display a cloud on the screen.

4.3   **Move the cursor to inside the BANK ACCOUNT box and click once.**

This will stretch an arrow from the cloud to the bank account. A text box will then appear.

4.4   **Type the word 'INCOME' and press ENTER.**

The model should now look like this:

The model shows that income flows into the Stock that is called BANK ACCOUNT

5. Add the Constant, Salary

5.1   **From the TOOL BAR, Select the *Variable Auxiliary/Constant Icon* (This looks like VAR and a pencil).**

        Click on the icon once.

5.2   **Move the cursor anywhere under the INCOME and click once.** (This will display a text box).

5.3   **Type the word 'Salary' and press ENTER.**

5.4   **From the TOOL BAR, Select the *Arrow Icon.*** (This looks like a curved arrow).

        Click on the icon once.

5.5   **Move the cursor onto Salary and click once.**
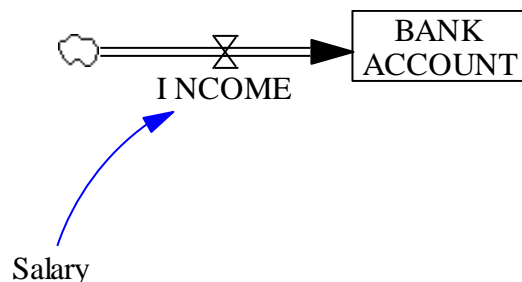
        This will create an arrow.

5.6   **Move the cursor to INCOME and click once.**

        This will position the end of the arrow.

        The circle on the line can be dragged to improve the curve of the arrow.

The model should now look like this:

A Salary payment causes the INCOME to Increase. Polarity needs to be added to the variables to show this relationship.
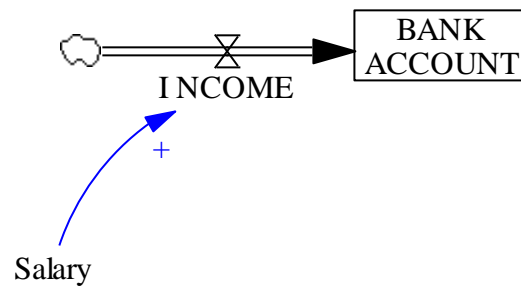
6. Adding Polarity

6.1   **From the TOOL BAR, Select the *Move / Size Words and Arrows Icon.* (This looks like a hand) and click on the icon once.**

6.2   **Move the cursor to the circle along the Salary arrow and click**

           once.

6.3   **RIGHT click the mouse once and a dialog box will appear.**

           Change the buttons to show a + polarity and click on OK.

           The model will now look like this:

Variables in simulation models are either EXOGENOUS or ENDOGENOUS.

Endogenous variables are part of at least one feedback loop.

Exogenous variables are those that are not part of a feedback loop.

Salary is an Exogenous variable.

7. Entering Equations

Equations provide the calculations for the simulation.

An equation requires three elements:

1. The calculation.
2. Units of measurement.
3. Documentation.

7.1 **From the TOOL BAR, Select the *Equation Icon*** (This looks like: $Y = X^2$). **Click on the icon once.**

All sections of the model which need an equation are highlighted.

7.2 **Click once on Salary.** A dialog box will be displayed.

7.3 In this case, we will assume Salary is constant at £1000 per month.

To the right of the **equal sign**, **type the number '1000'**.

7.4 To the right of **Units**, **type the words 'pounds/Month'.**

7.5 To the right of **Type**, **select CONSTANT from the menu.**

7.6 In the comments box, **type the phrase 'Salary is assumed to be constant and equal to £1000 per month in 2006.'.**

Press OK.

7.7 **Click once on INCOME.** A dialog box will be displayed,

7.8 In the dialog box, a list of available variables is displayed.

Click on SALARY. It will now appear next to the equal sign.

7.9 To the right of **Units**, **type: pounds/Month**

7.10   To the right of **Type**, **select AUXILIARY from the menu.**

7.11   In the comments box, **type the sentence 'The only income source is the monthly salary.'.**

Press OK

7.12   **Click once on BANK ACCOUNT.** A dialog box will be displayed,

Income already appears next to the equals sign.

The model knows that income is an inflow to salary.

7.13   Next to INITIAL VALUE, **type the number '100'.**

This says that the opening balance of the bank account is £100.

7.14   To the right of **Units**, **type the word 'pounds'.**

7.15   To the right of **Type**, **select LEVEL from the menu.**

7.16   In the comments box, **type the sentences 'The bank account has an opening balance of £100 in 2006. The balance of the bank account is equal to the bank balance plus the monthly income.'.**

Press OK.

8. Checking the Model

Vensim provides a tool to check the dimensional consistency of the model (i.e. that the units of measure are the same on both sides of equations).

8.1   Dimensional Consistency is checked by **holding down the Ctrl key on the keyboard and type the letter 'U'.**

If the dimensions are correct,

a message "**Units are A.O.K**." will be displayed.

Click once on ok.

The simulation can now be run.

If the dimensions are not correct,

a series of error messages will appear.

Go back and check the equations.

BANK ACCOUNT should have the dimension 'pounds'.

Everything else should have the dimension 'pounds/Month'.

Correct the dimensions and recheck the model.

9. Simulating the Model

9.1 **From the TOOL BAR, Select the *Run a Simulation Icon*.** (This looks like a running man).

Click on the icon once.
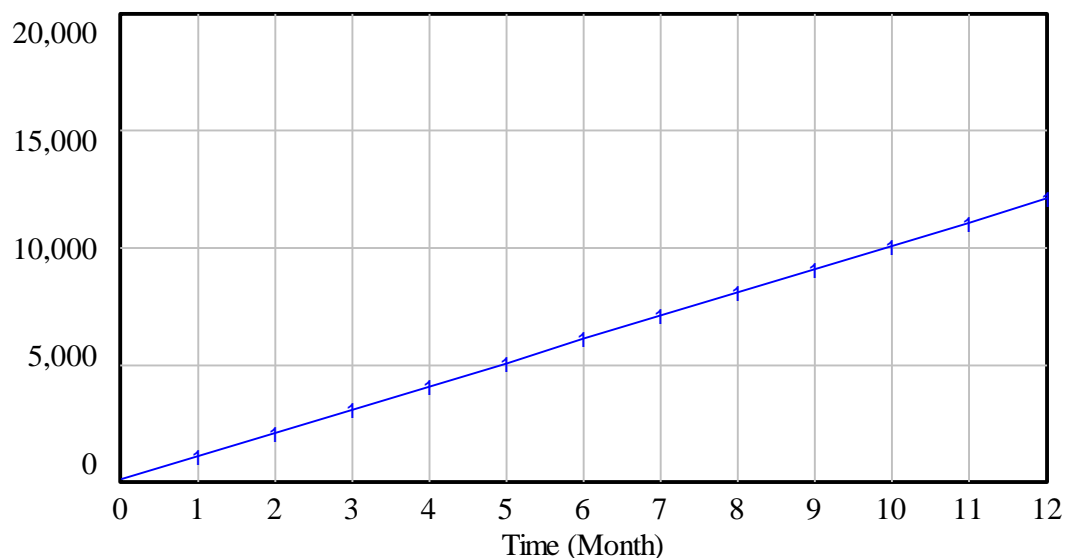
9.2 **Click on the BANK ACCOUNT.**

9.3 **From the left hand tool bar, Select the *Graph Icon*.** (This looks like a graph with 2 lines on it).

Click the icon once.

The following graph will be displayed.

The simulation shows that if you open a bank account with £100 and pay your salary of £1000 per month into the bank account, at the end of 12 months you will have £12,100 in your account.

BANK ACCOUNT

BANK ACCOUNT : Current ———————— pounds/Month

10 Minutes Reflection

Stop and look at the model developed so far.

A bank account has been represented as a STOCK that has a LEVEL.

Income FLOWS into the STOCK of bank account and increases the LEVEL of the bank account.

Salary is one VARIABLE that increases the FLOW of income into the STOCK of bank account.

Let's now assume you get paid interest on your bank account at 3%.

10. Add the Variable, Interest Payment

10.1   **From the TOOL BAR, Select the *Variable Auxiliary/Constant Icon*.** (This looks like VAR and a pencil).

Click on the icon once.

10.2   **Move the cursor anywhere under the BANK ACCOUNT box and click once.** (This will display a text box).

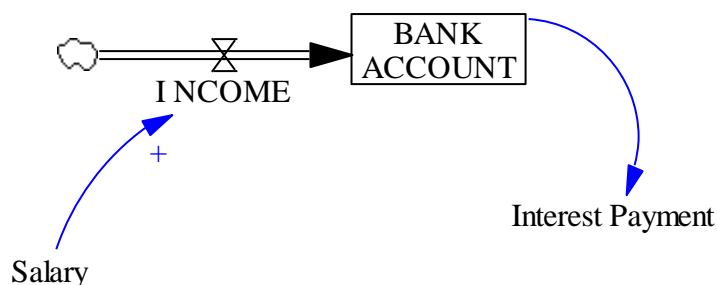10.3   **Type the words 'Interest Payment' and press ENTER.**

10.4   **From the TOOL BAR, Select the *ARROW Icon*** (This looks like a curved arrow). **Click on the icon once.**

10.5   **Move the cursor onto BANK ACCOUNT and click once.**

This will create an arrow.

10.6   **Move the cursor from BANK ACCOUNT to Interest Payment.**

The model should now look like this:

10.7   Add polarity.

From the TOOL BAR, Select the *Move / Size Words and Arrows Icon* (This looks like a hand) and **Click on the icon once.**

10.8   **Move the cursor to the circle along the Interest Payment arrow and click once.**

10.9   **RIGHT click the mouse once and a dialog box will appear.**

         Change the buttons to show a '+' (positive) polarity and click OK.

10.10   The Interest Payment contributes to the INCOME therefore an arrow needs to be added from Interest Payment to INCOME:

         From the TOOL BAR, Select the *Arrow Icon* (a curved arrow). Click on the icon once.

10.11   **Move the cursor onto Interest Payment and click once.** This will create an arrow.

10.12   **Move the cursor to INCOME and click once.** The circle on the line can be dragged to improve the curve of the arrow.

10.13   An Interest Payment increases the INCOME so positive polarity needs to be added:

         From the TOOL BAR, Select the *Move / Size Words and Arrows Icon* (a hand) and Click on the icon once.

10.14   **Move the cursor to the circle along the Interest Payment to INCOME arrow and click once.**

10.15   **RIGHT click the mouse once and a dialog box will appear.**

         Change the buttons to show a + (positive) polarity. Click OK.

The model should now look like this:
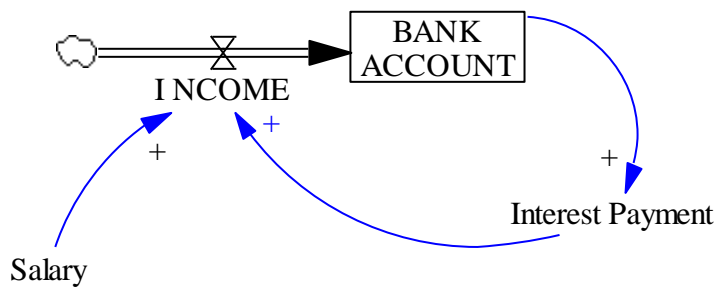
10.16 The interest accrued from the balance of the bank account *feeds back* into the bank account and increases the income earned. This creates a **positive feedback loop** which can be labelled.

From the TOOL BAR, Select the *Comments Icon* (This looks like the letters COM and a pencil). **Click the icon once.**

10.17 **Move the cursor to under BANK ACCOUNT but inside the loop created by the circular arrows and click once**. A dialog box will appear.

10.18 **From the SHAPE menu select 'Loop Clckwse'.**

10.19 In the comments box **type the word 'Interest'.**

Press OK.

The size of the loop can be changed by dragging the circle on the loop line.

10.20 The Interest Rate now needs to be added:

From the TOOL BAR, Select the *Variable Auxiliary/Constant Icon* (VAR and a pencil). **Click on the icon once.**

10.21 **Move the cursor anywhere under the Interest Payment and click once.** (This will display a text box).

Type the words 'Interest Rate' and press ENTER.

10.22   **From the TOOL BAR, Select the *Arrow Icon* (a curved arrow). Click on the icon once.**

10.23   **Move the cursor onto Interest Rate and click once.** This will create an arrow.

10.24   **Move the cursor from Interest Rate to Interest Payment.**

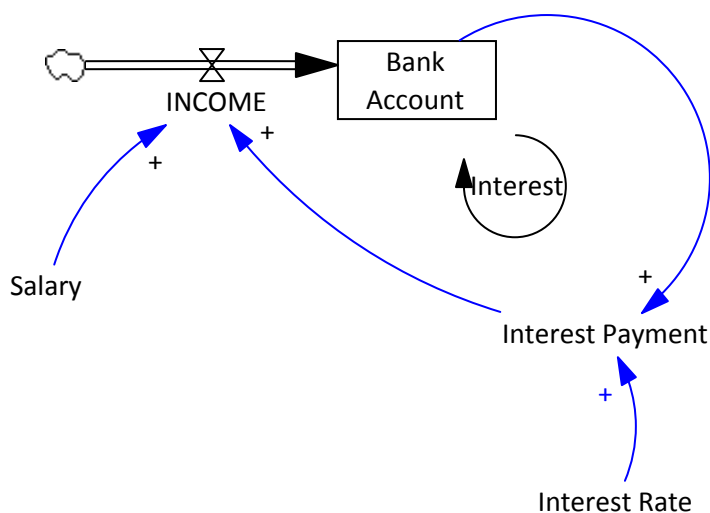10.25   Add polarity:

        From the TOOL BAR, Select the *Move / Size Words and Arrows Icon* (a hand) and Click on icon once.

10.26   **Move the cursor to the circle along the Interest Rate to Interest Payment arrow and click once.**

10.27   **RIGHT click the mouse once and a dialog box will appear.**

        Change the buttons to show a + (positive) polarity. Click OK.

The model should now look like this:

10.28   Now the equations need to be added:

From the TOOL BAR, Select the *Equation Icon* ($Y = X^2$). Click the Icon once.

All sections of the model which need an equation are highlighted.

10.29   **Click once on Interest Rate.** A dialog box will be displayed.

In this case, we will assume that the interest rate is 3% per year. As the model is set in months, we need to divide the rate by 12.

10.30 To the right of the **equal sign, type the number '0.0025'.**

10.31 To the right of **Type, select CONSTANT from the menu.**

10.32 To the right of **Units, type the phrase '1/Month'.**

10.33   In the comments box, **type the sentence ' The interest rate is 3% per year which is 0.0025 per month (i.e. 3% / 12).'.**

Press OK.

10.34   **Click once on Interest Payment.** A dialog box will be displayed.

10.35   The modelling tool has deduced that some of the variables may be needed in this equation and lists them on the right hand side.

Click once on BANK ACCOUNT, it will now appear next to the equal sign.

10.36   **Click once on the '*' (multiplication sign from the calculator).**

Click once on the words Interest Rate.

After the equal sign should now read:

BANK ACCOUNT*Interest Rate

10.37   To the right of **Type, select Auxiliary from the menu.**

10.38   To the right of **Units, type the phrase 'pounds/Month'.**

10.39   In the comments box, **type the sentence 'The interest payment is calculated by multiplying the balance of the bank account with the interest rate.'.**

Press OK.

10.40   **Click once on INCOME.** A dialog box will now be displayed:

10.41   The income equation now needs to be changed to show that income is the sum of salary and interest payment.

Click once next to the word Salary.

Click once on the + (plus sign from the calculator).

Click once on the words Interest Payment.

After the equal sign should now read:

Salary+Interest Payment

10.42   To the right of **Type**, **select Auxiliary from the menu.**

10.43   To the right of **Units, type the phrase 'pounds/Month'.**

10.44   In the comments box, **type the sentence 'Income comes from two sources, monthly salary and the interest payment from the bank account balance.'.**

Press OK.

10.45   Check for dimensional consistency:

Hold down the Ctrl key on the keyboard and type the letter 'U'.

If the dimensions are correct,

a message **"Units are A.O.K."** will be displayed.

Click once on OK. The simulation can now be run.

If the dimensions are not correct,

a series of error messages will appear.

Go back and check the equations.

BANK ACCOUNT should have the dimension 'pounds'.

Interest rate should have the dimension '1/Month'.

Everything else should have the dimension 'pounds/Month'.

Correct the dimensions and recheck the model.

10.46 The model can now be simulated:

From the TOOL BAR, Select the *Run a Simulation Icon* (Running man). Click on the icon once.

A message will appear asking if you want to overwrite the dataset. **Click on NO and type the file name 'Sim2' and click on SAVE.**

10.47 **Click on the BANK ACCOUNT.**

From the left hand TOOL BAR, Select *Graph Icon* (graph with 2 lines on it). Click the icon once.

The following graph will be displayed.
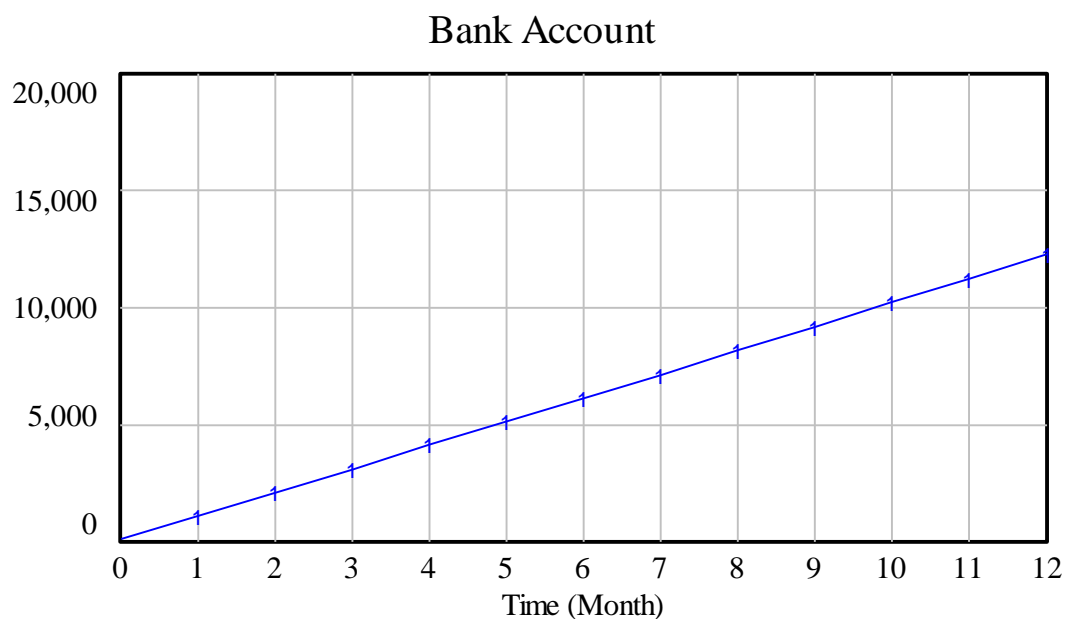
Bank Account

Bank Account : Current ———————— pounds

10 Minutes Reflection

Stop and look at the model developed so far.

A bank account has been represented as a STOCK that has a LEVEL.

Income FLOWS into the STOCK of bank account and increases the LEVEL of the bank account.

Interest is earned depending on the LEVEL of the bank account. The amount of interest is also affected by the variable called interest rate. Interest payments increase the FLOW of income into the bank account.

Interest payments earned from the LEVEL of the bank account FEED BACK into the bank account creating a POSITIVE FEEDBACK LOOP.

Each month we spend money so we need to show expenses on the model and investigate how spending money reduces our bank account.

11. Adding the Variable, Expenses

11.1   **From the TOOL BAR, Select the *Variable Auxiliary/Constant Icon* (VAR and a pencil). Click the icon once.**

11.2   **Move the cursor anywhere under and to the right of the Salary and click once.**
(This will display a text box).

11.3   **Type the word 'Expenses' and press ENTER.**

11.4   **From the TOOL BAR, Select the *Arrow Icon* (a curved arrow). Click the icon once.**

11.5   **Move the cursor onto Expenses and click once.** This will create an arrow. **Move the cursor from Expenses to INCOME.**

11.6   Expenses reduce income going into the bank account so a negative polarity has to be added.

From the TOOL BAR, Select the *Move / Size Words and Arrows Icon* (a hand) and click on the icon once.

11.7   **Move the cursor to the circle along the Expenses to INCOME arrow and click once.**

11.8   **RIGHT click the mouse once and a dialog box will appear.**

Change the buttons to show a '–' (negative) polarity and click on OK.

The model should now look like this:
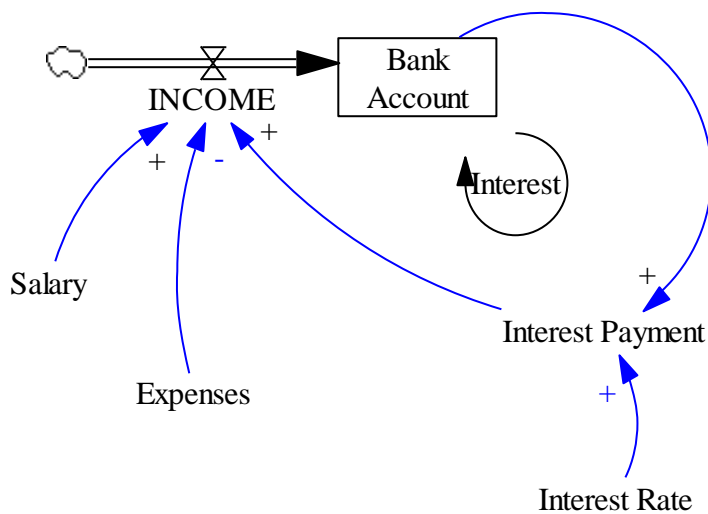
11.9 Equations need to be added:

From the TOOL BAR, Select the *Equation Icon* ($Y = X^2$). Click the icon once.

All sections of the model which need an equation are highlighted.

11.10 **Click once on Expenses.** A dialog box will be displayed.

11.11 In this case, we will assume that we spend £800 per month.

To the right of the **equal sign**, **type the number '800'.**

11.12 To the right of the **Type**, **select CONSTANT from the menu**

11.13 To the right of **Units**, **type the phrase 'pounds/Month'.**

11.14 In the comments box, **type the sentence 'The total monthly expenses are assumed to be £800 in 2006.'.**

Press OK.

11.15 **Click once on INCOME.** A dialog box will be displayed.

11.16   The equation should read:

       Salary+Interest Payment

Add brackets around the equation.

The equation should now read:

       (Salary+Interest Payment)

11.17   **Click once after the last bracket.**

Click on '−' (minus sign from calculator).

Click once on Expenses (from the right hand side).

The equation should now read:

       (Salary+Interest Payment)-Expenses

Add brackets around the equation.

The equation should now read:

       ((Salary+Interest Payment)-Expenses)

11.18   To the right of **Units**, **type the phrase 'pounds/Month'.**

11.19   To the right of **Type**, **select AUXILIARY from the menu.**

11.20   Edit the comments to read**: 'Income comes from two sources, monthly salary and the interest payment from the bank account balance (minus expenses).'.**

Press OK.

11.21 Check for dimensional consistency:

Hold down the Ctrl key on the keyboard and type the letter 'U'.

If the dimensions are correct,

       a message "**Units are A.O.K**." will be displayed.

       Click once on OK. The simulation can now be run.

If the dimensions are not correct,

       a series of error messages will appear.

Go back and check the equations.

BANK ACCOUNT should have the dimension 'pounds'.

Interest Rate should have the dimension '1/Month'.

Everything else should have the dimension 'pounds/Month'.

Correct the dimensions and recheck the model.

11.22 The model can now be simulated:

From the TOOL BAR, Select the *Run a Simulation Icon* (Running man). Click the icon once.

A message will appear asking if you want to overwrite the dataset. **Click on NO.** Type the filename **'Sim3' and press save.**

11.23 **Click on the BANK ACCOUNT**

From the left hand TOOL BAR, Select *Graph Icon* (graph with 2 lines on it). Click the icon once.

The following graph will be displayed.

Bank Account

Bank Account : Current ————————————— pounds
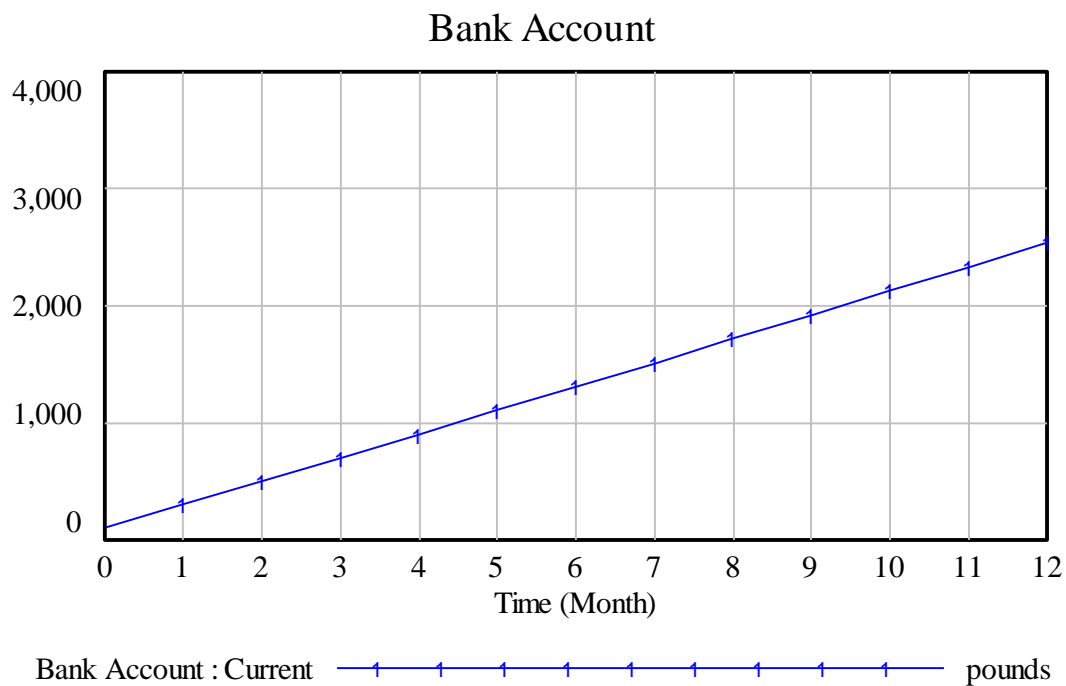
The graph shows the bank account over a 12 month period assuming that:

Salary is £1000 per month

Expenses are £800 per month

Interest is paid monthly from an annual rate of 3% per year.

These assumptions can be changed by editing the equations in the model.

12. Changing the Variables.

12.1 **From the TOOL BAR, Select the *Equation Icon* ($Y = X^2$). Click the icon once.**

12.2 **Click once on Expenses.** A dialog box will be displayed.

12.3 In this case, we will assume that we spend £1200 per month.

To the right of the equal sign, **replace the 800 by typing the number '1200' over it. Edit the comments box to reflect the change too.**

Press OK.

12.4 Check for dimensional consistency:

Hold down the Ctrl key on the keyboard and type the letter 'U'.

If the dimensions are correct,

      Click once on OK. The simulation can now be run.

If the dimensions are not correct,

      Go back and check the equations.
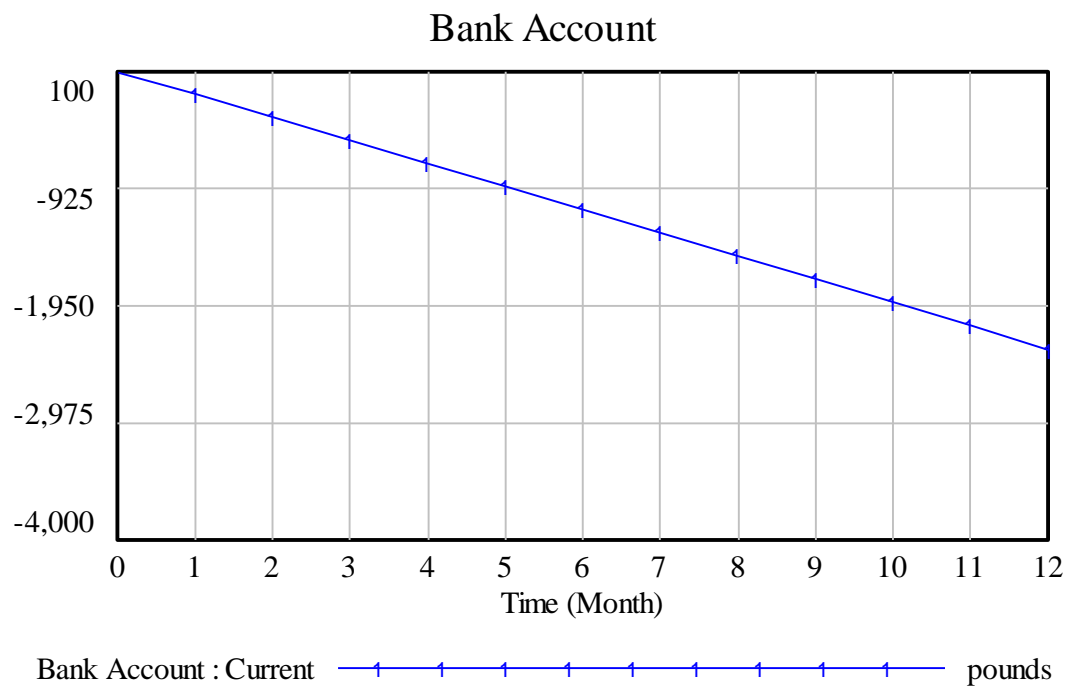
12.5 The model can now be simulated:

From the TOOL BAR, Select the *Run a Simulation Icon* (Running man). Click the icon once.

This simulation could be called **Sim4 and click on Save.**

12.6 **Click on the BANK ACCOUNT.**

From the left hand TOOL BAR, Select *Graph Icon* (graph with 2 lines on it). Click the icon once.

The following graph will be displayed.

Bank Account

The graph shows the bank account over a 12 month period assuming that:

Salary is £1000 per month

Expenses are £1200 per month

Interest is paid monthly from an annual rate of 3% per year.

12.7   Change the values to see what happens if:

Salary is £2000 per month

Expenses remain at £1200 per month

12.8   Change the values to see what happens if:

The interest rate increases to 3.5%.

12.9   Change the model settings **Select SETTINGS from the MODEL menu:**

Increase the final time to **24 months.**

10 Minutes Reflection

Stop and look at the model developed so far.

A bank account has been represented as a STOCK that has a LEVEL.

Income FLOWS into the STOCK of bank account and increases the LEVEL of the bank account.

Interest is earned depending on the LEVEL of the bank account and FEEDSBACK to increase the FLOW of income into the bank account.

The variable expenses reduces the FLOW of income into the STOCK of bank account and reduces the LEVEL of the bank account.

By changing the values of variables we can simulate what would happen if we earned a higher salary (or spent less) and so increased the FLOW of income into the STOCK of bank account. Exploring 'what if' scenarios can be used to help inform decision making (e.g. how much do you need to earn in order to save a million pounds? How many years do you need to work before the level of your bank account is high enough for you to retire?)

13. Using the Simulation to Develop Plans

Use the model to answer the following questions:

13.1   If the salary is £1750 per month and expenses are £1324 per month, how many months will it take to have a bank balance of £20,000?

13.2 If the starting balance for the bank account is £2000, the salary is £2000 per month and expenses are £2150 per month, in what month will the bank account have a negative balance?

13.3   If expenses are £1500 per month, how much salary is needed each month in order to have a bank balance of £10,000 at the end of two years of work?

14. Refine the Model

The model currently assumes a fixed salary. Modify the model so that the salary is calculated by two variables: number of hours worked multiplied by rate per hour.

> *10 Minutes Reflection*
>
> Stop and think how the model needs to be changed.
>
> Two variables need to be added to the model:
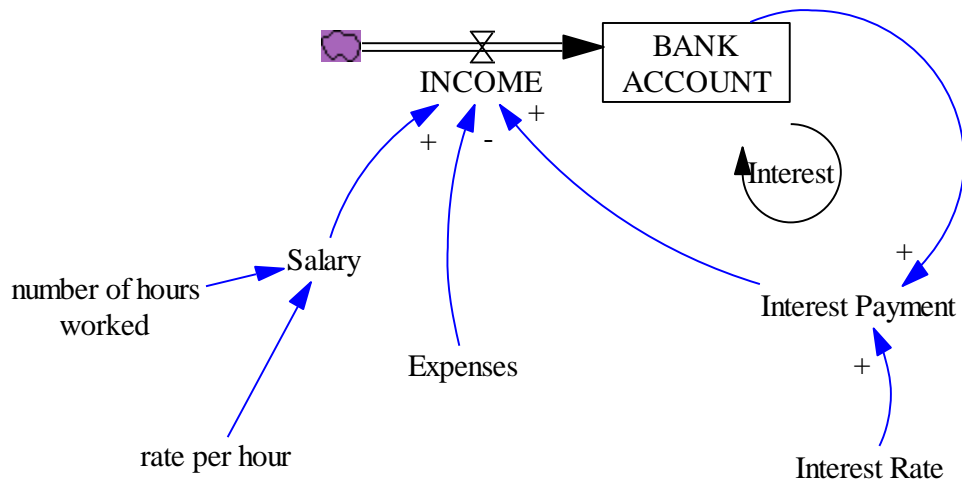> - number of hours worked.
> - rate per hour.
>
> These variables need to have arrows going from them to salary as they affect the salary.
>
> Each variable will need to have equations added to them.
>
> A bank account has been represented as a STOCK that has a LEVEL.
>
> Income FLOWS into the STOCK of bank account and increases the LEVEL of the bank account.

The model should now look like this:

Assume you work 37 hours at £5 per hour and add the equations to the model.

Use the model to answer the following questions:

14.1   How much would you earn in six months?

14.2   How many hours would you need to work to earn £20,000 per year?

14.3   If expenses are £1250 per month and you are paid £5 per hour, how many hours do
        you need to work to save £200 per month?

15. Save the New Model

15.1   **From the FILE Menu, Select SAVE AS**

        Type the file name 'model workbook1 bank account'.

        Click on SAVE button.

This is the end of the Workbook