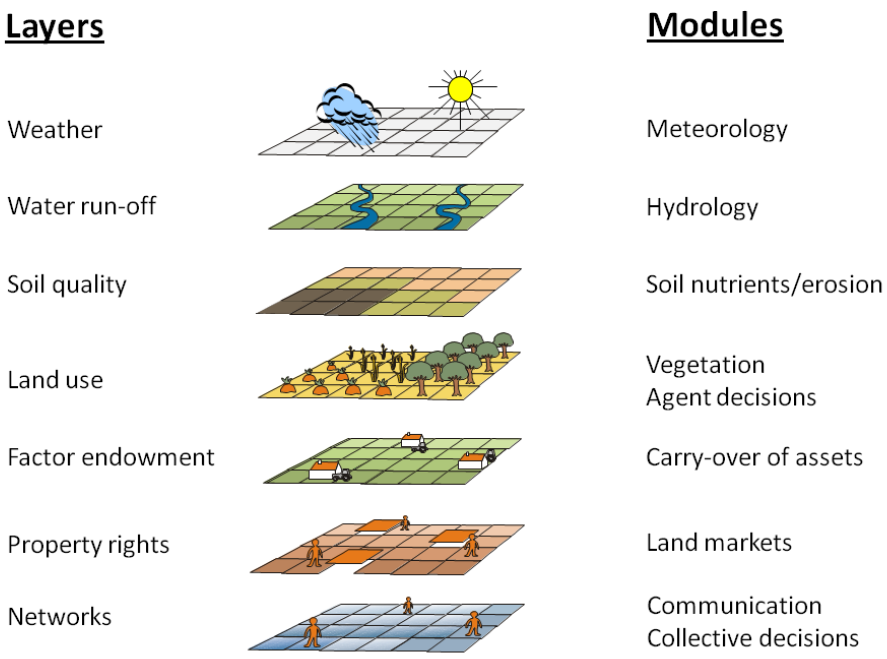
Mathematical Programming-based Multi-Agent Systems (MPMAS)

README for Mpmas Demo Version



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Thomas Berger, Evgeny Latynskiy, Christian Troost, William McClain

mas@uni-hohenheim.de

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1 Introduction

MPMAS is a software package for simulating land use change in agriculture and forestry. MPMAS uses mathematical programming to solve non-trivial land use decisions. With its mathematical programming decision-making component, MPMAS is firmly grounded in agricultural economics. It has been applied in a wide range of settings, including for irrigation water use in Chile and Ghana; soil fertility, poverty dynamics and producer organizations in Uganda; adaptation to climate change in Germany and Ethiopia; carbon sequestration in Brazil and innovation diffusion in Thailand and Vietnam.

2 Software requirements and installation

MPMAS is available as freeware software written in C++ that can be downloaded from http://mp-mas.uni-hohenheim.de. The software is a single executable file that does not need installation. Both Windows and Linux versions are available. The source code for MPMAS is not yet publicly available but in the process of becoming open-source software. Researchers who are interested in applying MPMAS and who need additional features not currently available in MPMAS can get in touch by emailing mas@uni-hohenheim.de.

This document describes how to use MPMAS under Windows 7 Professional with MS-Excel 2003 and 2007[1] and under Linux-Ubuntu with LibreOffice 5.1:

1. **Extract the compressed tutorial files "TUT_0_basic" to any location on the hard disk:** We suggest extracting the zip file to the main directory (usually C:/). The main folder of the tutorial package contains the various executables/Add-ins plus following subfolders:
    - *Input*: contains ASCII input files
    - *Out*: contains ASCII output files created when running MPMAS
    - *xlsInput*: contains Microsoft Excel workbooks from which the ASCII input files in the subfolder "input" are created. This is explained in the following sections.
    - *odsInput*: contains LibreOffice workbooks from which the ASCII input files in the subfolder "input" can also be created.
2. **Install the MPMAS macro tools in MS-Excel or LibreOffice**: The MPMAS macro tools are used to design scenarios, create input files, and analyze simulation outputs. Both under Windows and Ubuntu, these tools have to be installed before they can be accessed in the toolbars of MS-Excel and LibreOffice.

[1] Note that users have recently reported difficulties running console applications such as MPMAS on Windows 10.

2.1 Installing mpmas tool in MS-Excel

To install the add-in in MS Excel 2003, go to *Tools>Add-ins*. Click "*Browse*" and browse to the location of *mpmas.xla*. Select this file so that MPMAS appears in the list of Add-ins and make sure the checkbox is selected. The MPMAS add-in is now installed and any time you open Excel, the menu will appear as shown in Figure 1. In MS Office 2007 and later versions the add-in can be installed through *Office button>Excel options>Add-Ins>Go*.

To run macros, the security setting in Microsoft Excel (*Tools>Macros>Security* in MS Excel 2003 and *Office button>Excel options>Trust Center>Trust Center Settings* in MS Excel 2007) should be set to medium or low so that macros are enabled when opening files.

In order for *mpmas.xla* to function fully, it is necessary to make sure a few of your computer's settings are correct. First, the add-in requires the language settings be for English (US). To do this in Windows 8, use the *Charms* bar to search for *Control Panel*. In *Control Panel*, click on *Change Input Methods* under *Clock, Language, Region*. Click *Options* and change the default language to *English (US)*. In Windows 7 or earlier, navigate through the *Start* menu to the *Control Panel*. Under *Clock, Language* you can change the default region and language to *English (US)*.

It is also important that the full extension for each of the input files is shown in Window's Explorer (e.g. it should show *ScenarioManager.xls* rather than just *ScenarioManager*). As with the above, navigate to your version of Window's *Control Panel*. Click on *Appearance and Personalization* and then *Folder Options*. Navigate to *View>Advanced Settings* and make sure that the box "*Hide extensions for known file types*" is not checked.

Finally, make sure that Excel automatically calculates formulas and functions in your workbooks. In Excel 2007, this can be done by click on the *Formulas* tab. On the right of the screen, click on *Calculation Options* and choose "*Automatic*." In Excel 2003, navigate in the toolbar as such: *Tools>Options>Calculations* and choose *"Automatic*."

2.2 Installing mpmas tools in LibreOffice

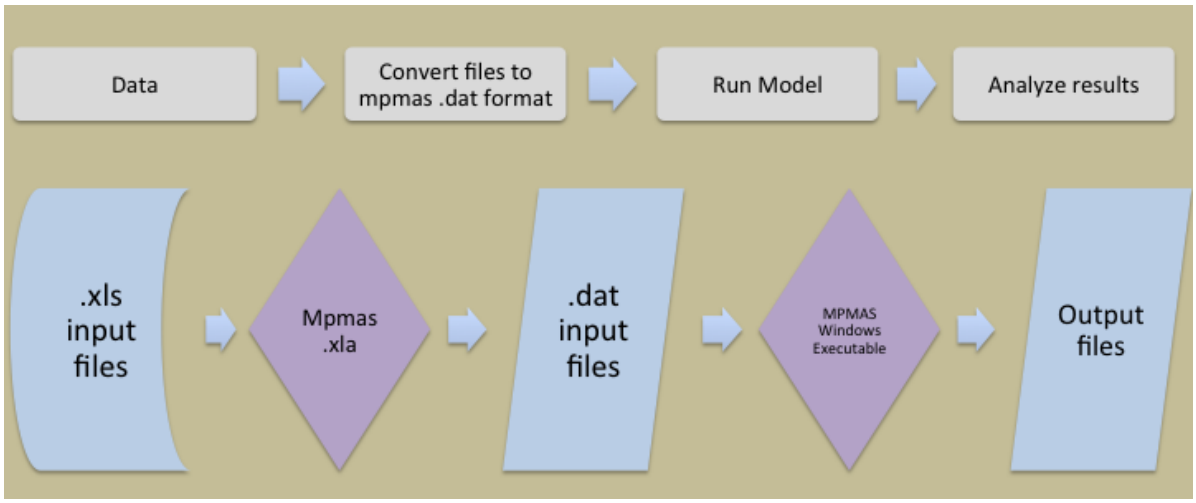
For use in Linux, we created an alternative MPMAS Add-in that has to be added as toolbar in LibreOffice-Calc. It will then create input files from the workbooks contained in the subfolder */odsInput*. To install the Add-in unzip *odsmpmastools* in the main folder and follow the instructions in the *Readme* file.

Note that this installation has been tested only with LibreOffice 5.1 under Ubuntu 14.04 and 16.04. We will probably not upgrade our MPMAS tools to newer versions of Libre/OpenOffice or to other Linux operating systems. The reason is that development of LibreOffice-Basic, the equivalent to Visual Basic in MS-Excel, has recently been discontinued.

3 MPMAS input files

MPMAS works with a set of text input files with the extensions *.dat* and *.txt* that are read and processed. Using the *mpmas macro tools* in MS-Excel or LibreOffice, it is possible to create these ASCII input files from the editable workbooks in */xlsInput* and */odsInput*, respectively. MPMAS is therefore different from many software applications, as the user is more or less free to organize the own data rather than the input data being entered through specially designed graphical user interfaces.

Input files are written in workbooks and contain one or more worksheets with data and sheets for calculations and notes. The use of MS-Excel/LibreOffice workbooks is convenient, as workbooks can be easily linked and contain separate sheets for calculations and documentation of the model. Comments, explanations, and whole calculations can thus be kept together with the final input data, which greatly simplifies its use.



Note: The procedure of creating *.dat* files from *.ods* workbooks is equivalent under LibreOffice-Linux.

The general design of MPMAS input files follows some conventions:

WORKSHEET NAMES: The name of each ASCII input file is derived from a scenario specified in *ScenarioManager.xls/ods* and the name of the respective worksheet. For example, if the prefix is set to "*A*" and the worksheet is named "*MILP*" then the ASCII input file will be called "*A_MILP*". The worksheet names can therefore not be changed.

ORDER OF THE WORKSHEETS: The workbooks used for MPMAS may contain multiple worksheets. The number of worksheets converted to ASCII is set in the upper table in *ScenarioManage.xls/ods*. If, say, two worksheets are to be converted then the workbook is opened and the first two sheets are taken. Worksheets with input data should therefore come first in the workbook, while worksheets with calculations and notes should come at the end.

RED-COLORED CELLS: Workbooks in MS-Excel and LibreOffice need to be well documented by including sufficient explanation in the worksheets. When converting the various worksheets into

ASCII, everything except those values required by MPMAS code should be deleted. Red-colored cells in Row 1 indicate that the *mpmas macro* tools should clear the corresponding columns while red-colored cells in Column A indicate that it should clear the corresponding rows. See Section 5.2 below for more information on using the *mpmas* tools complete this function.

TEXT COLORS: Different text colors are used to make clear how the cell is calculated.

- Blue numbers contain a formula and refer to cells in the same workbook
- Red numbers contain a formula and refer to cells in other workbooks
- Pink numbers are changed by ScenarioManager when converting files to ASCII
- **Black numbers** are normal cells without formulas

CELL NAMES: One of the advantages of using MS-Excel or LibreOffice is that workbooks can be linked. If workbooks are linked, then a change of a cell value in one workbook automatically changes this same value in all other workbooks linked to it. However, using references such as "*=BasicData!B2*" has the weakness that when inserting new columns or rows this reference is not updated in workbooks that are not currently open. This can be overcome by using textual cell names instead, e.g. give the cell B2 the name "Growth" using the 'Name Manager' feature of Excel or LibreOffice.

MPMAS has eight compulsory workbooks and six optional ones. The first workbook, *ScenarioManager,* is used to set up scenarios and to convert the input files to ASCII format. The second workbook is the mathematical programming tableau (*Matrix*), which organizes the decision-related data for all agents. This file is central to MPMAS. The function of all other input files is to calculate parameters that individual agents will insert in this matrix.

The remaining workbooks can be divided into three groups[2]:

- First, workbooks that create the population of agents, including their resource endowments (*Population.xls*), their spatial attributes (*Maps.xls*), and their knowledge of and access to innovations (*Network.xls*).
- Second, workbooks containing parameters that are constant over the simulation run, including general parameters (*BasicData.xls*), crop water requirements (*CropWat.xls*), and the distribution of water rights over agents (*WaterRights.xls*).
- Third, workbooks that simulate dynamics over time: demographic changes in agents' household size and composition (*Demography.xls*), growth of trees and changes in input requirements (*Perennials.xls*), growth of animals and changes in yields and input requirements over time (*Livestock.xls*), changes in market prices (*Market.xls*), changes in the fertility of soils (*Soils.xls*), and finally, changes in the water supply (*Routing.xls*).

[2] For simplicity, we write here ".xls" but always refer to both .xls in Mpmas_Excel and .ods in Mpmas_LibreOffice.

The different workbooks are given below:

Input file	Optional	Contents	
ScenarioManager	No	To create input files and to manage simulation experiments	
Matrix	No	A generic MP tableau (Mixed Integer Linear Program or MILP) that simulates the decision-making of agents.	
Population	No	Generates agent populations (household members of various ages, farm assets, liquidity, and other agent characteristics)	Initial conditions
Map	No	All spatial information including the boundary of the watershed, location of agents and agricultural plots.	
Network	No	Defines networks of innovation diffusion and determines for each network the level of diffusion at the start of the simulation.	
BasicData	No	Basic parameter values used in several components of the model.	Constant parameters
CropWat	Yes	Monthly crop water requirement for each crop activity included in the MP tableau and the efficiency of various irrigation methods.	
WaterRights	Yes	Defines the distribution of water between agents (water rights).	
Routing	Yes	The amount of irrigation water and precipitation for each month and for each year in the simulation run.	Model dynamics
Perennials	Yes	Annual yields, variable inputs, and capital needs of perennial crops.	
Livestock	Yes	Annual yields, variable inputs, and capital needs of farm animals.	
Soils	Yes	Soil fertility dynamics and crop yield response to soil nutrients.	
Market	No	All price information in the objective function of the MP tableau: prices for buying agricultural inputs, farm gate selling prices, and the off-farm labor wage rate.	
Demography	No	The labor supply for each age of an agent household member and defines population dynamics such a the probability of dying and the probability of giving birth.	

4 Functions of mpmas macro tools

MPMAS uses ASCII format for its input files. These pure text files are not convenient to edit, since they can't contain any headers, comments or formulas. The *Mpmas macro tools* help to convert your spreadsheets to the respective formats used by MPMAS. In this way, you first create your model input in Excel/LibreOffice and then convert it to ASCII using the macro tools. In addition, the tools contain features that allow you to optimize creation of simulation scenarios, analyze MPMAS output and solve stand-alone mixed-integer programming problems.

Mpmas.xla and the equivalent add-in in LibreOffice serve the following functions:

- Deleting existing input and output files
- Converting *.xls* (*.xlsx, .xlsm*) or *.ods* files to ASCII text format
- Quick creation of simulation scenarios
- Running the program executable (*mpmas.exe* or *mpmas*)
- Solving a stand-alone MIP-problem (*mpmasMipSolver.exe* or *mpmasMipSolver*)
- Analyzing saved agent LPs (*.mip* and *.err* files)
- Solving a single-agent problem with different sets of RHS values and objective functions: useful for debugging and sensitivity analysis (*XSingleAgents.xls/ods*)
- Analyzing simulation results for all agents (*XResults.xls/ods*)

5 Using mpmas.xla[3]

5.1 Deleting existing input and output files

MPMAS input files are located in the subfolders */input/dat* (text files with *.dat* extension) and */input/gis* (ASCII maps). MPMAS output files are located in the subfolders */out* (text files with *.out* extension) and */out/test* (additional text output written out, when using MPMAS test flags).

Mpmas.xla can be used for quick deletion of input and output files. In order, to do so you have to open *ScenarioManager.xls*. Clicking on "Delete all files" in the MPMAS dropdown menu will delete all input and output files from the respective folders. "Delete input files (.dat/.gis)" will delete all input files. "Delete input files (.dat)" will delete only *.dat* input files and leave the files from */input/gis* subfolder (ASCII maps). If input maps for MPMAS were created in GIS and not Excel, it is thus possible to only delete *.dat* files and keep the map files in */input/gis* as long as no changes are required. In this case it is also necessary to set the switch for including maps to zero in the top left-hand box (cell D8) of the Scenario Manager.

"Delete output files" will delete all output files, respectively.

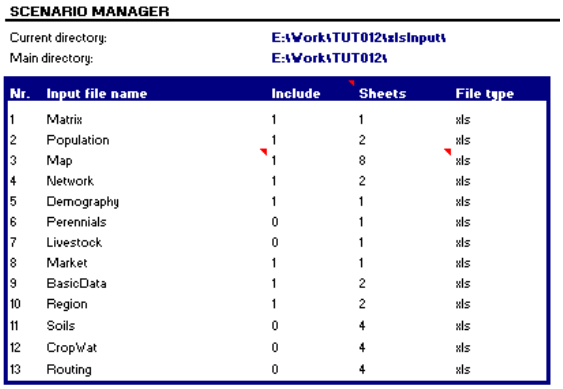
5.2 Converting .xls (.xlsx, .xlsm) files to ASCII format

Mpmas.xla can convert your commented Excel input files from the */xlsInput* folder to the model input text files and write them down into the respective subfolder of */input*

This operation can be executed by clicking on "Create input files" in the MPMAS dropdown menu while having *ScenarioManager.xls* open. The spreadsheet *ScenarioManager.xls* tells *mpmas.xla*

[3] And the LibreOffice tools that process files with *.ods*

which Excel workbooks to convert. The user must specify which workbooks in the top right table of the *ScenarioManager.xls* spreadsheet:



SCENARIO MANAGER

Current directory: E:\Work\TUT012\xls\input\
Main directory: E:\Work\TUT012\

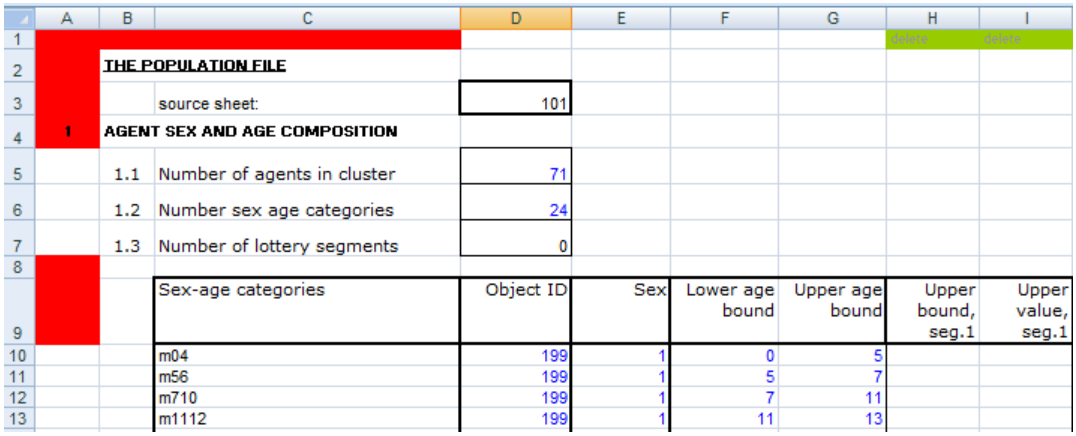
Nr.	Input file name	Include	Sheets	File type
1	Matrix	1	1	xls
2	Population	1	2	xls
3	Map	1	8	xls
4	Network	1	2	xls
5	Demography	1	1	xls
6	Perennials	0	1	xls
7	Livestock	0	1	xls
8	Market	1	1	xls
9	BasicData	1	2	xls
10	Region	1	2	xls
11	Soils	0	4	xls
12	CropWat	0	4	xls
13	Routing	0	4	xls

The entry in the cell "*Current directory*" specifies the path to the folder containing the Excel input files (*.xla* inserts the path to the location of *ScenarioManager.xls* file). The cell "*Main directory*" specifies the main directory of the model folder, which is where the /input and /out subfolders are located (*.xla* inserts here the path to the parent folder "*Current directory*"). Normally, these paths are updated automatically when you open *ScenarioManager.xls*. If they were not automatically updated, then click on “Set path names” in the MPMAS dropdown menu.

The column "*Input file name*" contains the names of the standard Excel files with MPMAS input. In the column "*Include*" the user has to specify which Excel workbooks *.xla* has to convert to the MPMAS input format. Values of the "*Include*" column may take either 0 ("not include") and 1 ("include"). Entries in column "*Sheets*" tell *.xla* how many worksheets (counting from the left) have to be converted from the respective workbooks. Column "*File type*" specifies the extension of Excel input files (*.xls, .xlsx, .xlsm* etc).

After clicking on “Create input files,” the *.xla* will open the included files and worksheets and convert them to model input one by one. The transformations that *.xla* will perform, when converting files to model format is the following:

1. Update cells listed in *ScenarioManager.xls* with provided values (procedure explained in the next section)
2. Update links
3. Delete formulas and break links
4. Delete all rows and columns that contain cells either (i) marked with a red color or (ii) marked with green color and containing the word "delete" inside. For example, in the picture below rows 1 to 4 and 8 to 9 will be completely deleted, as well as columns A to C, H and I. Other information will appear in the MPMAS input files. This way the user may have comments and headers in his Excel files that won't be included to the MPMAS input files.



		THE POPULATION FILE						
		source sheet:	101					
1	AGENT SEX AND AGE COMPOSITION							
	1.1	Number of agents in cluster	71					
	1.2	Number sex age categories	24					
	1.3	Number of lottery segments	0					
		Sex-age categories	Object ID	Sex	Lower age bound	Upper age bound	Upper bound, seg.1	Upper value, seg.1
		m04	199	1	0	5		
		m56	199	1	5	7		
		m710	199	1	7	11		
		m1112	199	1	11	13		

5. Save a copy of the worksheet (the original Excel files will remain unchanged) as a file in */input* folder under the name <scenario name><worksheet name>.<input file extension> (*.txt* for Map files and *.dat* for others). If files with same names already exist in the */input* folder the user will be asked: *"Input files for the Scenario already exist in […]. Would you like to delete these input files first?"* Answering "Yes" will delete all input files (both *.dat* and *.txt*) from */input* folder and save the newly created files there. When answering "No", the user will be asked to approve whether he wants to replace the same files names with the new ones (files with other filenames will remain).

In addition, when converting files, *.xla* applies extra specific treatments for the Excel workbooks *Matrix.xls* and *Map.xls*:

1. **Matrix:** Information used by the solver (objective function coefficients, integer info, etc.) is copied and pasted to the specific places in the input file *MILP.dat*. Therefore, *.xla* expects some predefined cell and range names to be present in the MILP spreadsheet of the *Matrix.xls* workbook. The full list of required names can be found in the *Matrix.xls* included in the tutorial model (see sheet "*Notes*"). Using the 'Name Manager' feature in Excel 2007 ("Formulas" tab) you can see which cells and ranges these names are referring to. If you forget to specify one of the required names, *.xla* should normally remind you when converting *Matrix.xls*.

2. **Map:** For the *Map.xls* workbook the *.xla* converts the worksheet only once, irrespective how many scenarios the user has specified (creation of scenarios is explained further). This is done due to the fact that the map normally doesn't vary between scenarios of one set.

5.3 Quick creation of simulation scenarios

ScenarioManager.xls and *mpmas.xla* can be used together to quickly create several simulation scenarios at a time. For creation of simulation scenarios, the user must use the bottom table in the *ScenarioManager.xls*:

Nr.	Parameter	Input file name	Cell name	Unit	Scenarios 0	1
0	Include			[1/0]	1	1
1	Prefix			string	Scen1	Scen2
2	Note				Actual prices	100% price increase
3	Maize (kg)	Market	p_maize	number	2.00	4.00
4	Bean (kg)	Market	p_bean	number	3.00	6.00

This table needs to always have two top rows. The "*Include*" row under the parameter column tells *.xla* which scenarios to convert (value of one in the column for the respective scenarios means "convert" and 0 "not convert). The user can specify more scenarios, but convert only some of them. The "*Prefix*" row under the parameter column contains the prefix of scenario, which will be used in the names of *.dat* input files (naming was explained above).

The rows below, which contain entries in the columns "*Input file name*" and "*Cell name*" will be used to define the simulation scenarios. Here, you specify in which input files *.xla* has to update which cells and which values to use for that. The *.xla* will take the values in Scenario columns and replace with them the entries in cells from "*Cell name*" in Excel files specified in "*Input file name*" column. For the example above, the *.xla* would replace the value of the cell named "*p_maize*" in the Market file with 2.00 for the "*Scen1*" scenario and with 4.00 for the "*Scen2*" scenario.

5.4 Running the MPMAS

Once all input text files have been created, one can proceed to running MPMAS. The *.xla* automatically generates a batch file called *run_windows.bat*, using the information provided in the top right table of *ScenarioManager.xls*:

Information	General
Last used by	evgeny
Date	7/24/2012
Time to convert	6.71 seconds
Create batch file [1/0]	1
Options	
	Windows
Location executable	E:\Work\TUT012\
Name of executable	mpmas.exe
	Unix
Location executable	
Name of executable	
Prefix	

The cells "*Location executable*" and "*Name executable*" point to the MPMAS executable (*mpmas.exe*). The cell "*Options*" contains information on the additional test flags that must be used when running MPMAS. Note that the flags must be entered in Excel with ' in front (e.g. '-T1) (the full list of flags is provided in the "TestFlags" spreadsheet of *ScenarioManager.xls*, see below for more information).

It is possible to run the batch file from the *.xla* menu directly ("Run MP-MAS"). Alternatively, one

can execute the batch file *run_windows.bat* directly from the model folder by clicking on it. Also, the file can be executed from the Windows command prompt (*cmd.exe*). The advantage of using the command prompt is that the command prompt terminal does not disappear once the model run finishes or if the model crashes. This may make it easier to identify possible error sources.

If the model runs to the end, the message "Success: Simulation experiment [...] completed" will appear. A text file with the name of the scenario with the extension *.err* is created when the model runs. Here, one can also find hints for possible error sources.

The output files are written to the directory */out*. If test flags are used, additional test files will be written to the subdirectory *./out/test*. Some of these test files allow for identification of input errors.

Important test flags: '-T34' and '-T1' are often used flags if you have an error message. Write these flags in *ScenarioManager.xls* under "*Options*" (cell J10). For Excel to read it you must enter it as such "*'-T34 '-T1*". The corresponding outputs will be written to the folder out/test. "*'-T82*" will print the Header Line to the MPMAS output files.

5.5 Solving a standalone MILP-problem (*mpmasMipSolver*)

The "Solve Matrix" option of the *.xla* add-in can be used to solve standalone MILP problems. The purpose of this feature is to give the model user the possibility to test the matrix before running the entire MPMAS model, which, especially at a more advanced stage of the modeling process, can take considerable time and have a much more complex validation process than in the standalone mode. For this, the second executable that comes with the model, *mpmasMipSolver.exe* is used. To run *mpmasMipSolver.exe,* it is necessary to have the *Matrix.xls* workbook opened. The RHS-vales need to be entered by hand in the matrix file (they are only used in the "Solve Matrix" mode and automatically overwritten when using *mpmas.exe*). Click on "Solve Matrix" in the drop-down add-in menu. In the dialogue box that appears, the solving mode needs to be chosen. It is recommended to use mode 4. To use the "Solve Matrix" option *Matrix.xls* has to be in the same format as when using MPMAS.

After your problem was solved with *mpmasMipSolver.exe*, the *.xla* should normally automatically import the solution vector to the respective cells of your Matrix file (as is done when using the standard Excel-solver). Also the solution is saved in the *.pri* file in the same folder with *mpmasMipSolver.exe.* Use this file if the auto-import failed.

5.6 Analyzing saved agent MP (*.mip* files)[4]

While the MPMAS model is running, certain agent MP matrices might be saved automatically as *.mip* files, e.g. if the MP was infeasible or the objective function value was too low. If certain agent problems are not saved automatically, it still might be useful to analyze and re-solve MP for

[4] This feature is currently not available under LibreOffice-Ubuntu.

particular agents in order to look for mistakes in *Matrix.xls*, trying different RHS values, upper and lower bounds, etc. To save MP of particular agents you enter the farmstead ID with a negative sign at the bottom table in *ScenarioManager.xls*:

Parameter	Input file name	Cell name	Unit	1
Include			[1/0]	1
Prefix			string	BSL
Note				Baseline
Number of simulation years	Market	SimYears1	integer	8
Number of simulation years	Region	SimYears	integer	8
Market price factor	Market	price_factor	number	1
Debugging				
Save a matrix [0]	BasicData	milp0	integer	-67
Save a matrix [1]	BasicData	milp1	integer	0

Create your new input files and run MPMAS. The agent MILPs are saved in the *./out/test* folder

The name of the files provide information on the scenario, the time period, agent ID and consumption stage in the following order:

<Scenario>_<Time Period>_<Agent ID>_<Consumption Stage>. *.mip* files contain the matrix information, *.pri* files contain the solution vector.

Depending on which type of consumption module you are working with (basic or advanced consumption module), you will generate two or three sets of files corresponding to investment, production and—if advanced consumption—consumption stages. The lower number will always correspond to the investment stage, then the next one to the production, and the next one to consumption.

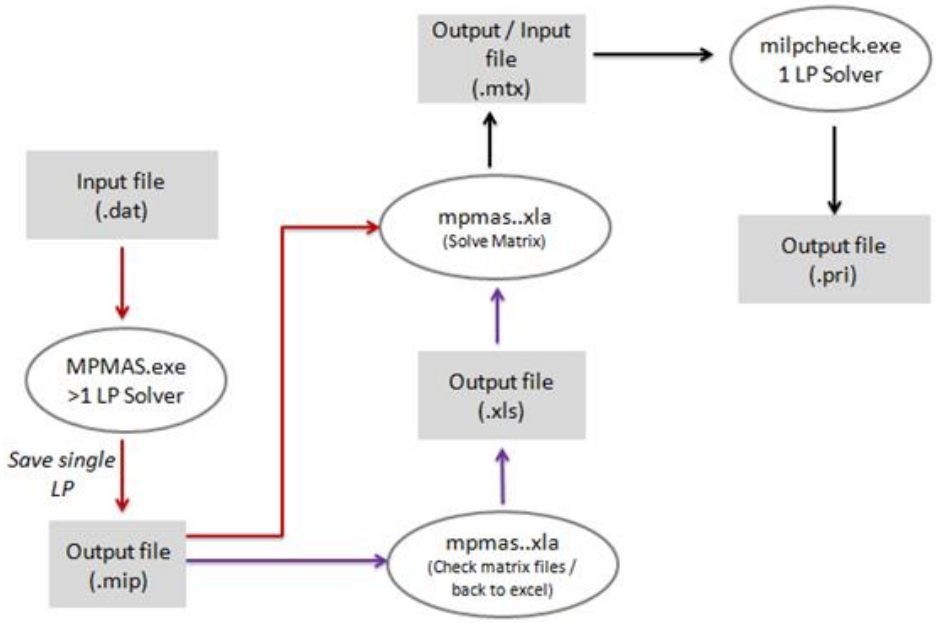
Now you can analyze the single agent matrix and solve it again. For doing so there are two options available:

Option 1: Using *mpmas.xla*, select *"*Check matrix files (err./.mtx)*"* in the MPMAS dropdown menu, then select the MP files to be solved and click *"*Solve again*"*. It is recommendable to solve in Mode 4. Three different files per re-solved matrix will be generated in the MPMAS main directory. *.mtx* files contain the matrix information, *.tst* also the matrix information with some headers, and *.pri* files contain the solution vector.

Option 2: Instead of directly solving the MP problem again, it is possible to use the option *"*Check matrix files (err./.mtx),*"* selecting *"*Go back to Excel*"* to convert your files to *.xls* first. The converted *.xls* files will be saved in the out/test folder. For solving the matrix again, locate the excel file in the main MPMAS directory and rename it as "*Matrix.xls*". Open the file and use the "Solve Matrix" option of *mpmas.xla*. The matrix will solve again and the solution, solution vector and RHS will be updated. To check if the values were correctly updated, compare them with the values contained in the related *.pri* file.

NOTE: when converting files back to excel and resolving again, the newly created *.mtx* files only capture the first 15 decimals of a number. This can lead to slightly different solutions.

The following graph provides a quick overview of the process:



5.7 Solving a matrix with different RHS values and objective functions

The *XSingleAgents.xls* workbook allows users to solve single-agent MILPs with *mpmasMipSolver.exe* with alternative RHS and objective function values (e.g. to perform farm-level sensitivity analysis).

In the sheets "*RHS*" and "*Orow*" of *XSingleAgents.xls* you can define sets of RHS-value and objective function values respectively. Than in sheet "*XSingleAgents*" you can set up your sensitivity scenarios by naming them and specifying which sets to choose. To run the scenarios you have to click on “Solve XSingleAgents.xls” in the MPMAS menu. For each scenario, new solution vectors (saved in *.pri*) will be calculated and automatically imported to the worksheet "*Analyze*". A further result summary with fewer variables can be found in the "*Results*" sheet (only in Excel).

5.8 Analyzing results for all agents (*Xresults.xls*)

MPMAS generates a huge amount of data. In order to compact and analyze this information several alternatives exist. Statistical packages, such as STATA, can be used and scripts (*.do* files) are available.

In addition, the add-in feature “XResults.xls” is handy to gain an insight into model results. This tool requires that the workbook *XResults.xls* be open and that information on the location of files, the scenario name, etc. is provided in the sheet “*Analyzer*.” When clicking on the button in the add-in task menu, *XResults.xls* imports data from the output files, which contains the solution vector (u) and the available and used resources (k). The description for the variables of the

imported data can be taken from *Matrix.xls*.

For first hand analysis of results in MPMAS, the *xResults.xls* sheet is very useful. Please note that you have to update the headers in your *XResults.xls* file whenever you added/changed our deleted activities and constraints in your matrix (just copy and paste from your matrix to your u and k sheets in *XResults.xls*)

However, for big models and detailed analysis of results, the use of standard economics software, such as STATA, R or SAS, are recommended for analysis.

5.9 Other functions

Under "Other tools" in the *.xla* menu you can find some additional useful functions (not all functions are currently implemented in LibreOffice).

Options "Find blank cells in selection" and "Fill blank cells with zeros" allow the user to quickly locate blank cells in MILP (which will cause errors when using *mpmas.exe* or *mpmasMipSolver.exe*) and fill them with zeros. The option "Insert rows/columns" allows the user to add the necessary number of columns to the MILP. "Freeze panes in Matrix" will quickly freeze panes in the top left corner of your MILP.

6 MPMAS Output files

Scenario results are written to the folder */out*. A number of plain text files are created that contain different information on results from the model. MPMAS assigns a number of different codes to help understand what type of output is generated, which are then placed as the suffix of the nine output files. They are given in the following table:

Table 1 Output file suffix codes

Nr.	suffix	Description
1	_a_t	Agent exit data (e.g., due to bankruptcy or out-migration)
2	_d_t	The diffusion of innovations
3	_k_t	Available and used resources
		With _xk_t for agents having exited the population
4	_p_t	Agent performance (e.g. income, depreciation, liquidity, etc.)
		With _xp_t for agents having exited the population
5	_u_t	The solution vector (primal)
		With _xu_t for agents having exited the population
6	_y_t	Crop yield information (only when having yields endogenous in the model)
7	_w	Sector water data
8	_l	Land data
9	diff	Innovation diffusion over all periods in one file

For the files with the suffix _p, _k, and _u (performance, available and used resources, and objective function solution), the format of the output file is relatively the same. Each row contains information on a separate agent (given by the Agent ID). The first thirteen columns for each p, k and u output file are the same, given in the following table:

Table 2 Standard columns in _p, _k and _u files

Nr.	Short name	Explanation
1	typ_str	Type of information: 1: performance data (p-file); 2: primal solution (u-file); 3: objective values (u-file) 4: available capacity (resources) (k-file) 5: actually used capacity (k-file)
2	aID	Identifies the agent
3	catchID	Identifies the (sub-)catchment or village
4	secID	Identifies the agent sector
5	fstID	Identifies the farmstead as read from the file <map.xls>
6	popID	ID of agent population
7	clustID	Identifies the population cluster (i.e., each sheet in the file <population.xls> is a separate segment
8	nwID	Identifies the network through which innovations diffuse (e.g., separate networks of large-scale commercial and family farms)
9	segID	Identifies the innovation segment (0,1,2,3,4)
10	expectID	Type of (price and yield) expectations
11	colorID	Color of grid cell in the map
12	xcoord	x-coordinate of the farmstead (column number in raster map)
13	ycoord	y-coordinate of the farmstead (row number in raster map)

The _p file contains important information about the performance of different agents. These are often important metrics when analyzing results from different scenarios. The different codes for farm performance outcomes are given in the following table:

Table 3 Outcomes contained in performance files

Nr.	Short name	Explanation
1	nplots	The number of plots owned by the agent
2	totgrossmargin	Total gross margin. The optimum solution of each LP, yet excluding the future prices.
3	cashflow	The net cash flow or net cash surplus = total gross margin – Fixed costs – Transport costs
4	income	Household income = Net cash flow + appreciation of assets – depreciation of assets + income transfers – debt service
5	valueadded	Value added
6	equitycapital	Equity capital
7	Paymtoland	Payments to land
8	Relfactorpayment	Relative factor payments
9	onfarmlabor	On farm labor use
10	onfarmcapital	On farm capital use
11	interestpaid	Interest paid on investments (specified in Network.xls)
12	distancecost	Distance costs (specified in BasicData.xls)
13	addtranscost	Transport costs (specified in BasicData.xls)
14	consumption	Value of household consumption (specified in Market.xls)
15	liquidmeans	Liquid means at the end of the period
16	migration	Migration decision (see above)
17	lastlp	Last LP (investment, production, or consumption)

The _a file contains important information on agent population dynamics, in particular bankruptcy or out-migration. The basic structure of the _a output file is given in the following table:

Table 4 Basic structure of _a output file

Nr.	Short name	Explanation
1	GiveUp	Type of information: 14=planning error 15=reason of exit
2	nwID	Number of separate networks
3	segID	Segment ID
4	f_per_seg	Number of agents remaining in each segment
5	nr_m_plan	Number of planning mistakes
6	nr_giveup_vol	Number of agents that give up voluntarily (e.g., migrate out due to high opportunity costs outside farming)
7	nr_giveup_invol	Number of agents that were forced to give up (e.g., bankruptcy)

Different codes indicate what the reasons are for an agent exits the population:

Table 5 Codes for reasons agents exit population

Code	Explanation
-1	**Bankruptcy / forced migration:** The liquid means are less than zero.
-2	**Voluntary migration:** The opportunity cost of labor (defined in Network.xls) is greater than the returns from the farm times the migration full factor (also defined in Network.xls)
-3	**No household members left:** Because of mortality and fertility rates (defined in Demography.xls) the agent has lost all household members and thereby seizes to exist.
-4	**No active labor force:** The labor supply is zero (the labor supply for each age and sex category is defined in Demography.xls).
-5	**No adult labor force:** The agent household has only children. Note that the difference between children and adults is defined in Demography.xls.

The _d file contains information on innovation diffusions, which may be important as MPMAS is often used to assess adoption of innovations across an agent population. The information contained in this file is given in the following table:

Table 6 Structure of _d output file

First column ID	Explanation
06	Number of users of an innovation (absolute value)
07	The total acreage of all users of an innovation (absolute value)
08	Total Gross Margins (absolute value)
09	Value Added (absolute value)
10	users (percentage)
11	acreages of users (percentage)
12	Total Gross Margins (percentage)
13	Value Added (percentage)

7 Further reading and references

The main reference when using/citing MPMAS is the journal publication of Schreinemachers and Berger (2011) in *Environmental Modeling & Software*. More documentation, including an expanded manual introducing the technical functions and structure of MPMAS, can be found on https://mp-mas.uni-hohenheim.de/documentation. In addition, a number of country-specific technical documentations can be found on the website, with a range of different applications:

Germany: Troost, C. 2014. MPMAS Central Swabian Jura (Version 3.1) – Model Documentation.
Includes information on: Agent expectations and learning; biogas production; additional livestock output (manure); policy interventions; farm succession; land markets; agent populations

Uganda: Latynskiy, E. 2014. Agent-based simulation modeling for analysis and support of rural producers organizations in agriculture.
Includes information on: Producers' organizations and institutions; consumption preferences (food and non-food); remittances
Schreinemachers, P. 2006. The (Ir)relevance of the Crop Yield Gap Concept to Food Security in

Developing Countries With an Application of Multi Agent Modeling to Farming Systems in Uganda.
Includes information on: Three-step decision process; three-step budgeting process; use of an Almost-Ideal Demand System

Ethiopia: Berger, T., S. Gbegbelegbe, E. Latynskiy, W. McClain, K. Tesfaye, C. Troost, and T. Wossen. 2014. Adaptation of farm-households to increasing climate variability in Ethiopia: Simulation with MPMAS.
Includes information on: Coping strategies; measuring food security; farmer adaptation strategies

Thailand: Schreinemachers, P., A. Sirjinda, C. Potchanasin, T. Berger and S. Praneetvatakul. 2009. An agent-based land use model of the Mae Sa watershed area, Thailand. Detailed model documentation. MPMAS Version 2.0.
Includes information on: Pesticide use, soil loss from erosion

Additional information, applications and technical issues can be found in publications by the MPMAS developer team:

Berger, T., Troost, C., Wossen, T., Latynskiy, E., Tesfaye, K., Gbegbelegbe, S. Can smallholder farmers adapt to climate variability, and how effective are policy interventions? Agent-based simulation results for Ethiopia. Agricultural Economics (online first), doi: 10.1111/agec.12367

Wossen, T., Berger, T., Haile, M., Troost, C. Impacts of Climate Variability and Food Price Volatility on Household Income and Food Security of Farm Households in East and West Africa. Agricultural Systems (online first), doi 10.1016/j.agsy.2017.02.006)

Latynskiy, E., Berger, T., 2017. Assessing the income effects of group certification for smallholder coffee farmers: Agent-based simulation in Uganda. Journal of Agricultural Economics (online first), doi: 10.1111/1477-9552.12212

Carauta, M., Latynskiy, E., Mössinger, J., Gil, J., Libera, A., Hampf, A., Monteiro, L., Siebold, M., Berger, T., 2017. Can preferential credit programs speed up the adoption of low-carbon agricultural systems in Mato Grosso, Brazil? Results from bioeconomic microsimulation. Regional Environmental Change (online first), doi: 10.1007/s10113-017-1104-x

Grovermann, C., Schreinemachers, P., Riwthong, S., Berger, T, 2017. 'Smart' policies to reduce pesticide use and avoid income trade-offs: An agent-based model applied to Thai agriculture. Ecological Economics 132, 91-103

Latynskiy, E., Berger, T., 2016. Networks of rural producer organizations in Uganda: What can be done to make them work better? World Development 78, 572-586

Bannwarth, M., Grovermann, C., Schreinemachers, P., Ingwersen, J., Lamers, M., Berger, T., Streck, T., 2016. Non-hazardous pesticide concentrations in surface waters: An integrated approach simulating application thresholds and resulting farm income effects. Journal of

Environmental Management 165, 298-312

Troost, C., Berger, T., 2015. Dealing with uncertainty in agent-based simulation: Farm-level modelling of adaptation to climate change in Southwest Germany. American Journal of Agricultural Economics 97, 833-854

Troost, C., Walter, T., Berger, T., 2015. Climate, energy and environmental policies in agriculture: Simulating likely farmer responses in Southwest Germany. Land Use Policy 46, 50-64

Arnold, T., Troost, C., Berger, T., 2015. Quantifying the economic importance of irrigation water reuse in a Chilean watershed using an integrated agent-based model. Water Resources Research 51, 648-668

Wossen, T., Berger, T., 2015. Climate Variability, Food Security and Poverty: Agent-Based Assessment of Policy Options for Farm Households in Northern Ghana. Environmental Science & Policy 47, 95-107

Wossen, T, Berger, T., Swamikannuh, N., Ramilan, T., 2014. Climate variability, consumption risk and poverty in semi-arid Northern Ghana: Adaptation options for poor farm households. Environmental Development 12, 2-15

Quang, D.V., Schreinemachers, P., Berger, T., 2014. Ex-ante assessment of soil conservation methods in the uplands of Vietnam: An agent-based modeling approach. Agricultural Systems 123, 108–119.

Berger, T., Troost, C., 2014. Agent-based Modeling of Climate Adaptation and Mitigation Options in Agriculture. Journal of Agricultural Economics, 65, 323-348.

Latynskiy, E., Berger, T., Troost, C., 2014. Assessment of Policies for Low-Carbon Agriculture by means of Multi-Agent Simulation. In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), Proceedings of the 7th International Congress on Environmental Modeling and Software, June 15-19, San Diego, California, USA.

Marohn, C., Schreinemachers, P., Quang, D.V., Berger, T., Siripalangkanont, P., Nguyen, T.T., Cadisch, G., 2012. A software coupling approach to assess low-cost soil conservation strategies for highland agriculture in Vietnam. Environmental Modeling & Software 45, 116–128

Troost, C., Calberto, G., Berger, T., Ingwersen, J., Priesack, E., Warrach-Sagi, K., Walter, T., 2012. Agent-based modeling of agricultural adaptation to climate change in a mountainous area of South West Germany. In: Seppelt, R., Voinov, A., Lange, S., Bankamp, D. (Eds.), International Environmental Modeling and Software Society (iEMSs): 2012 International Congress on Environmental Modeling and Software: Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany

Schreinemachers, P., Berger, T., 2011. An agent-based simulation model of human environment interactions in agricultural systems. Environmental Modeling & Software 26, 845-859.

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ante assessment of tree crop innovations: litchis in northern Thailand. Agricultural Economics 41(6), 519–536.

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Schreinemachers, P., Berger, T., 2006. Land-use decisions in developing countries and their representation in multi-agent systems. Journal of Land Use Science 1(1), 29-44.

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