Solving applications of Linear Programming with Excel SOLVER

Susana Barreiro
February 27

ISA - Applied Operational Research - 2024/2025

APPLIED OPERATIONAL RESEARCH

Question 2.

Test - 25 May 2016

A farmer has the following resource endowments: 500 acres of land, 1500 hours of family labour and 120000 € of capital investment. She can use these resources to grow the following crops: corn, sorghum, wheat and soybeans. Any crop should not occupy more than 250 acres. Assume that the farmer works to maximize profit (revenue minus costs) from the production of these crops. She expects the following in terms of prices, crop yields, costs and labor requirements.

Crop	Price (€/bushel)	Yield (bushel/acre)	Cost (€/acre)	Labor Requirement (hours/acre)
Corn	2.75	120	250	3.25
Sorghum	2.65	100	200	3.00
Wheat	3.15	105	245	3.15
Soybeans	6.75	45	230	3.30

1. Formulate the problem as a linear program.
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?
3. Which constraints are binding? How do you interpret each binding constraint?
4. By how much should sorghum's current profit per acre increase in order for the optimal solution to change? Sorghum's current profit per acre decrease would change the optimal solution?
5. What is the shadow price for each constraint? How do you interpret this value?
6. What is the range of feasibility for the maximum number of hours of family labour with respect to the shadow price? How do you interpret this range?
7. How much the profit would change if one acre of soybeans were forced into the current optimal solution?

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Soybeans	6.75	45	230	3.30

1. Formulate the problem as a linear program.

$$\text{Maximize } Z = 80x_1 + 65x_2 + 85.75x_3 + 73.75x_4$$

$$x_1 + x_2 + x_3 + x_4 \leq 500$$
$$x_1 \leq 250$$
$$x_2 \leq 250$$
$$x_3 \leq 250$$
$$x_4 \leq 250$$
$$3.25x_1 + 3.00x_2 + 3.15x_3 + 3.30x_4 \leq 1500$$
$$250x_1 + 200x_2 + 245x_3 + 230x_4 \leq 120000$$
$$x_1, x_2, x_3, x_4 \geq 0$$

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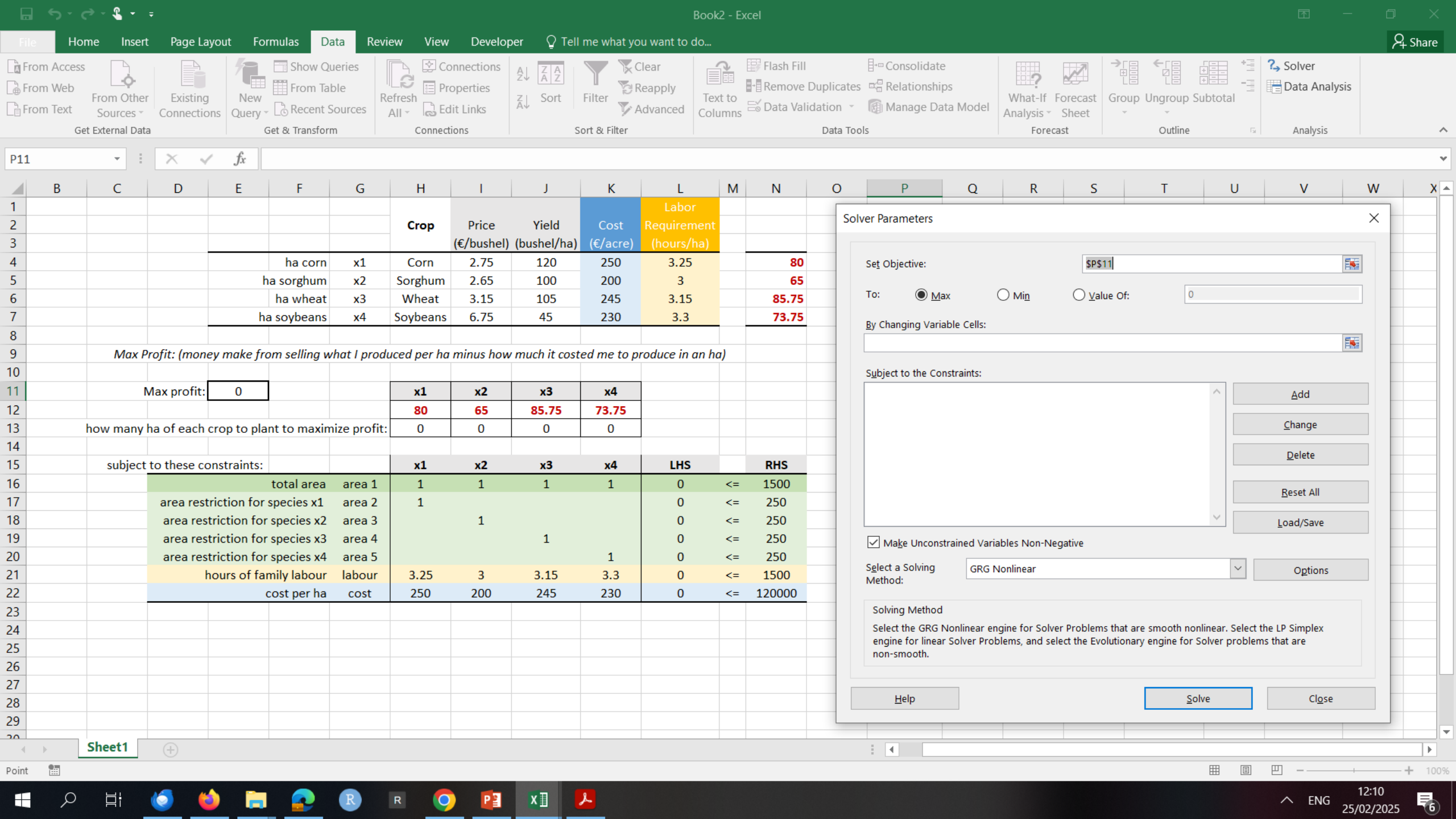
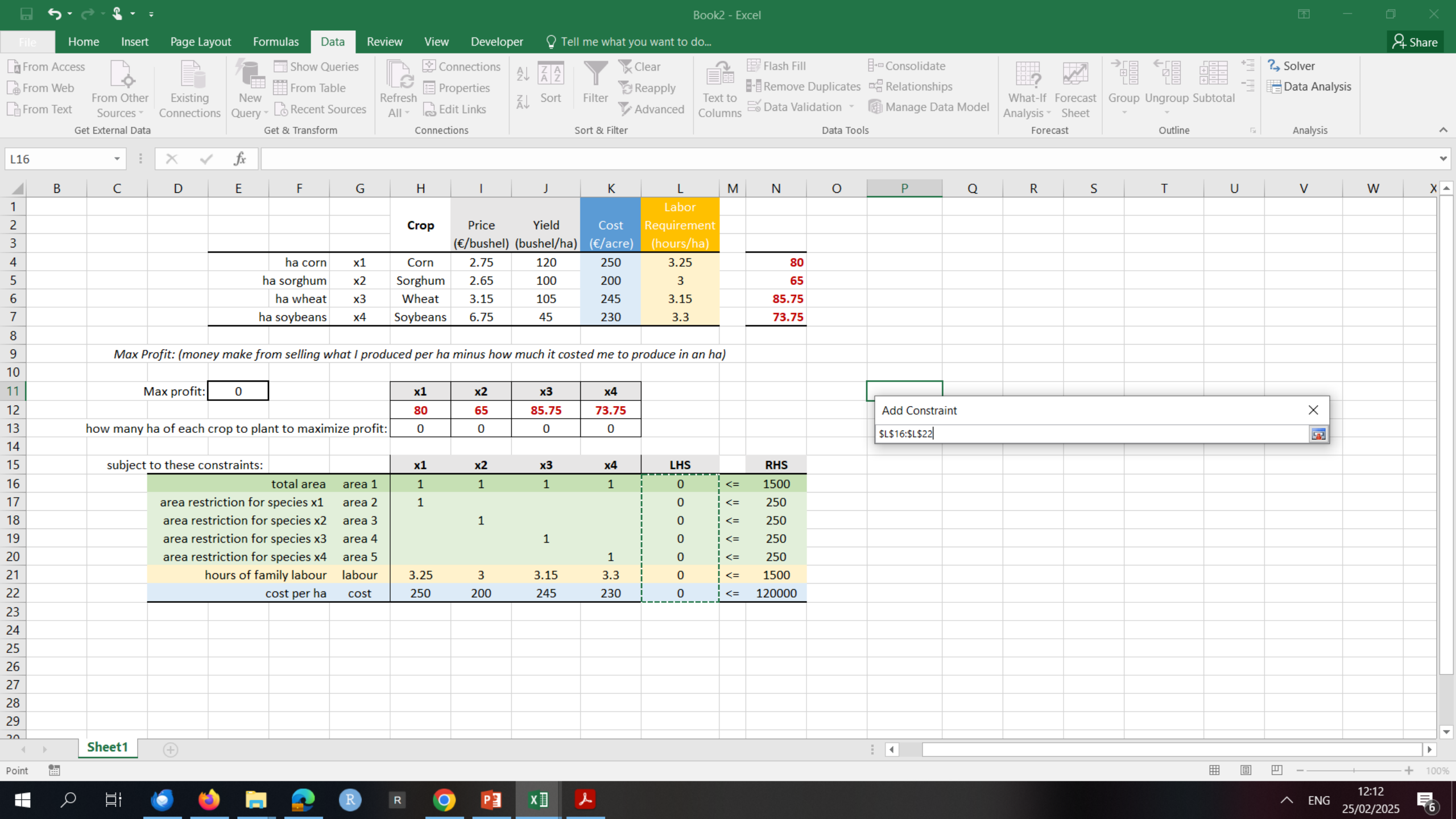
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?


Book2 - Excel
File Home Insert Page Layout Formulas Data Review View Developer Tell me what you want to do... Share
From Access From Web From Text From Other Sources Existing Connections Get External Data
New Query Show Queries From Table Recent Sources Get & Transform
Refresh All Connections Properties Edit Links Connections
Sort Filter Clear Reapply Advanced Sort & Filter
Text to Columns Flash Fill Remove Duplicates Data Validation Consolidate Relationships Manage Data Model Data Tools
What-If Analysis Forecast Sheet Forecast
Group Ungroup Subtotal Outline
Solver Data Analysis Analysis
P11
Crop
Price (€/bushel)
Yield (bushel/ha)
Cost (€/acre)
Labor Requirement (hours/ha)
ha corn x1 Corn 2.75 120 250 3.25 80
ha sorghum x2 Sorghum 2.65 100 200 3 65
ha wheat x3 Wheat 3.15 105 245 3.15 85.75
ha soybeans x4 Soybeans 6.75 45 230 3.3 73.75
Max Profit: (money make from selling what I produced per ha minus how much it costed me to produce in an ha)
Max profit: 0
x1 x2 x3 x4
80 65 85.75 73.75
how many ha of each crop to plant to maximize profit: 0 0 0 0
subject to these constraints: x1 x2 x3 x4 LHS RHS
total area area 1 1 1 1 1 0 <= 1500
area restriction for species x1 area 2 1 0 <= 250
area restriction for species x2 area 3 1 0 <= 250
area restriction for species x3 area 4 1 0 <= 250
area restriction for species x4 area 5 1 0 <= 250
hours of family labour labour 3.25 3 3.15 3.3 0 <= 1500
cost per ha cost 250 200 245 230 0 <= 120000
Solver Parameters
Set Objective: $P$11
To: Max Min Value Of: 0
By Changing Variable Cells:
Subject to the Constraints:
Add Change Delete Reset All Load/Save
Make Unconstrained Variables Non-Negative
Select a Solving Method: GRG Nonlinear Options
Solving Method
Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.
Help Solve Close
Sheet1
Point
ENG 12:10 25/02/2025



	Crop	Price (€/bushel)	Yield (bushel/ha)	Cost (€/acre)	Labor Requirement (hours/ha)	
ha corn	x1	Corn	2.75	120	250	3.25	80
ha sorghum	x2	Sorghum	2.65	100	200	3	65
ha wheat	x3	Wheat	3.15	105	245	3.15	85.75
ha soybeans	x4	Soybeans	6.75	45	230	3.3	73.75

Max Profit: (money make from selling what I produced per ha minus how much it costed me to produce in an ha)

Max profit:	0	x1	x2	x3	x4
		80	65	85.75	73.75
how many ha of each crop to plant to maximize profit:		0	0	0	0

subject to these constraints:		x1	x2	x3	x4	LHS		RHS
total area	area 1	1	1	1	1	0	<=	1500
area restriction for species x1	area 2	1				0	<=	250
area restriction for species x2	area 3		1			0	<=	250
area restriction for species x3	area 4			1		0	<=	250
area restriction for species x4	area 5				1	0	<=	250
hours of family labour	labour	3.25	3	3.15	3.3	0	<=	1500
cost per ha	cost	250	200	245	230	0	<=	120000

Book2 - Excel

File | Home | Insert | Page Layout | Formulas | Data | Review | View | Developer | Tell me what you want to do... | Share

From Access | From Web | From Text | From Other Sources | Existing Connections — Get External Data
New Query | Show Queries | From Table | Recent Sources — Get & Transform
Refresh All | Connections | Properties | Edit Links — Connections
Sort | Filter | Clear | Reapply | Advanced — Sort & Filter
Text to Columns | Flash Fill | Remove Duplicates | Data Validation | Consolidate | Relationships | Manage Data Model — Data Tools
What-If Analysis | Forecast Sheet — Forecast
Group | Ungroup | Subtotal — Outline
Solver | Data Analysis — Analysis

N16

	B	C	D	E	F	G	H	I	J	K	L	M	N
1													
2							**Crop**	Price (€/bushel)	Yield (bushel/ha)	Cost (€/acre)	Labor Requirement (hours/ha)		
3													
4					ha corn	x1	Corn	2.75	120	250	3.25		80
5					ha sorghum	x2	Sorghum	2.65	100	200	3		65
6					ha wheat	x3	Wheat	3.15	105	245	3.15		85.75
7													
8													
9		*Max*											
10													
11													
12													
13		how many											
14													
15		subject											
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													

Sheet1

Solver Results

Solver found a solution. All Constraints and optimality conditions are satisfied.

Reports: Answer, Sensitivity, Limits

(•) Keep Solver Solution
( ) Restore Original Values

[ ] Return to Solver Parameters Dialog
[ ] Outline Reports

OK | Cancel | Save Scenario...

Reports

Creates the type of report that you specify, and places each report on a separate sheet in the workbook

Solver Parameters

Set Objective: $E$11

To: (•) Max ( ) Min ( ) Value Of: 0

By Changing Variable Cells: $H$13:$K$13

Subject to the Constraints:

$L$16:$L$22 <= $N$16:$N$22

Add | Change | Delete | Reset All | Load/Save

[✓] Make Unconstrained Variables Non-Negative

Select a Solving Method: Simplex LP | Options

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Help | Solve | Close

Point

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Book2 - Excel

Insert | Page Layout | Formulas | Data | Review | View | Developer | Tell me what you want to do... | Share

Calibri 11 | Wrap Text | General | Conditional Formatting | Format as Table | Normal | Bad | Good | Neutral | Calculation | Check Cell | Insert | Delete | Format | AutoSum | Fill | Clear | Sort & Filter | Find & Select

Font | Alignment | Number | Styles | Cells | Editing

			Crop	Price (€/bushel)	Yield (bushel/ha)	Cost (€/acre)	Labor Requirement (hours/ha)	
ha corn	x1	Corn	2.75	120	250	3.25		80
ha sorghum	x2	Sorghum	2.65	100	200	3		65
ha wheat	x3	Wheat	3.15	105	245	3.15		85.75
ha soybeans	x4	Soybeans	6.75	45	230	3.3		73.75

ax Profit: (money make from selling what I produced per ha minus how much it costed me to produce in an ha)

Max profit: **38976**

	x1	x2	x3	x4			
	80	65	85.75	73.75			
many ha of each crop to plant to maximize profit:	219.2	0	250	0	the amount of resource spent	the amount of resource available	the amount of resource unspent

bject to these constraints:		x1	x2	x3	x4	LHS		RHS			
total area	area 1	1	1	1	1	469.230769	<=	1500	1031		
area restriction for species x1	area 2	1				219.230769	<=	250	31		
area restriction for species x2	area 3		1			0	<=	250	250		
area restriction for species x3	area 4			1		250	<=	250	0	*resource fully used*	**binding constraint**
area restriction for species x4	area 5				1	0	<=	250	250		
hours of family labour	labour	3.25	3	3.15	3.3	1500	<=	1500	0	*resource fully used*	**binding constraint**
cost per ha	cost	250	200	245	230	116057.692	<=	120000	3942		

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Sheet1

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APPLIED OPERATIONAL RESEARCH

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A farmer has the following resource endowments: 500 acres of land, 1500 hours of family labour and 120000 € of capital investment. She can use these resources to grow the following crops: corn, sorghum, wheat and soybeans. Any crop should not occupy more than 250 acres. Assume that the farmer works to maximize profit (revenue minus costs) from the production of these crops. She expects the following in terms of prices, crop yields, costs and labor requirements.

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Wheat	3.15	105	245	3.15
Soybeans	6.75	45	230	3.30

1. Formulate the problem as a linear program.
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?

Once applied solver we find out the values of the decision variables (x1, x2, x3, x4) that maximize the profit of the farmer and the corresponding profit.

The optimal solution tells the farmer that to maximize profit she should plant:

219.2 ha of x1 (corn) **0** ha of x2 (sorghum) **250** ha of x3 (wheat) **0** ha of x4 (soybeans)

(x1, x2, x3, x4) = (**219.2, 0, 250, 0**) and that this would allow a profit of **38 976 €**

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1. Formulate the problem as a linear program.
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?
3. Which constraints are binding? How do you interpret each binding constraint?

The Answer Report

Microsoft Excel 16.0 Answer Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53
Result: Solver found a solution. All Constraints and optimality conditions are satisfied.
Solver Engine
Engine: Simplex LP
Solution Time: 0.063 Seconds.
Iterations: 2 Subproblems: 0
Solver Options
Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$E$11	Max profit:	0	38975.96154

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$H$13	how many ha of each crop to plant to maximize profit: x1	0	219.2307692	Contin
$I$13	how many ha of each crop to plant to maximize profit: x2	0	0	Contin
$J$13	how many ha of each crop to plant to maximize profit: x3	0	250	Contin
$K$13	how many ha of each crop to plant to maximize profit: x4	0	0	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$L$16	area 1 LHS	469.2307692	$L$16<=$N$16	Not Binding	1030.76923
$L$17	area 2 LHS	219.2307692	$L$17<=$N$17	Not Binding	30.7692308
$L$18	area 3 LHS	0	$L$18<=$N$18	Not Binding	250
$L$19	area 4 LHS	250	$L$19<=$N$19	Binding	0
$L$20	area 5 LHS	0	$L$20<=$N$20	Not Binding	250
$L$21	labour LHS	1500	$L$21<=$N$21	Binding	0
$L$22	cost LHS	116057.6923	$L$22<=$N$22	Not Binding	3942.30769

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Sheet1

The initial, optimal solutions (x1, x2, x3, x4), amount of (un)spent resources can be read across tables

The ***Objective Cell* table** tells us the starting value of the objective function (Z) when *Solver* was applied and the optimal value after *Solver*

The ***Variables Cells table*** shows the values of the decision variables (x1, x2, x3, x4) for the initial solution and the optimal solution

The ***Constraints* table** provides information regarding the restrictions applied to each of the decision variables and resources (*Formula*), providing indication on which are the limiting resources - the binding constraints - that will have a **positive shadow price** (*the table does not the shadow price value*)

The Answer Report

Microsoft Excel 16.0 Answer Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53
Result: Solver found a solution. All Constraints and optimality conditions are satisfied.
Solver Engine
Engine: Simplex LP
Solution Time: 0.063 Seconds.
Iterations: 2 Subproblems: 0
Solver Options
Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$E$11	Max profit:	0	38975.96154

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$H$13	how many ha of each crop to plant to maximize profit: x1	0	219.2307692	Contin
$I$13	how many ha of each crop to plant to maximize profit: x2	0	0	Contin
$J$13	how many ha of each crop to plant to maximize profit: x3	0	250	Contin
$K$13	how many ha of each crop to plant to maximize profit: x4	0	0	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$L$16	area 1 LHS	469.2307692	$L$16<=$N$16	Not Binding	1030.76923
$L$17	area 2 LHS	219.2307692	$L$17<=$N$17	Not Binding	30.7692308
$L$18	area 3 LHS	0	$L$18<=$N$18	Not Binding	250
$L$19	area 4 LHS	250	$L$19<=$N$19	Binding	0
$L$20	area 5 LHS	0	$L$20<=$N$20	Not Binding	250
$L$21	labour LHS	1500	$L$21<=$N$21	Binding	0
$L$22	cost LHS	116057.6923	$L$22<=$N$22	Not Binding	3942.30769

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Sheet1

The initial, optimal solutions (Z, x1, x2, x3, x4), amount of (un)spent resources can be read across tables

A **binding constraint** is one whose alteration causes a subsequent change in the optimal solution.

This is actually great for business managers and programmers alike because once they obtain their optimal solution, they can always tweak it using the constraint to achieve the desired goal!

Changing the value of a **non-binding constraint** effect on the optimal solution obtained.

Non-binding constraints have shadow price of zero

spent + *unspent* = *Total amount of resources originally available*

1500
250
250
250
250
1500
120000

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Soybeans	6.75	45	230	3.30

1. Formulate the problem as a linear program.
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?
3. Which constraints are binding? How do you interpret each binding constraint?

The binding constraints are those representing the resources that are fully used (area to plant wheat and labour time) and indicate that any change to these constraints will lead to a change in the optimal solution

$$x_3 \leq 250$$

$$3.25x_1 + 3.00x_2 + 3.15x_3 + 3.30x_4 \leq 1500$$

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2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?
3. Which constraints are binding? How do you interpret each binding constraint?
4. By how much should sorghum's current profit per acre increase in order for the optimal solution to change? Sorghum's current profit per acre decrease would change the optimal solution?

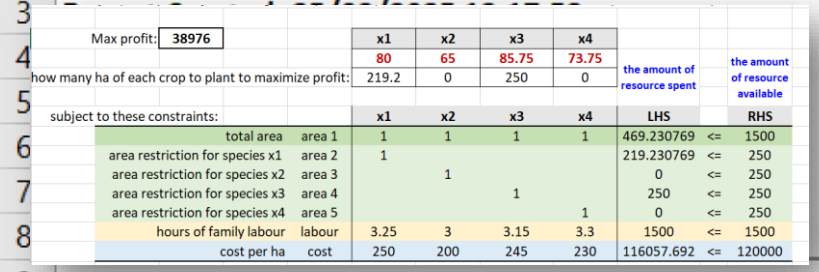
Now we need to go into the output reports generated by solver:

- Answer report
- Sensitivity report

Sensitivity Report

Microsoft Excel 16.0 Sensitivity Report

Worksheet: [Book2]Sheet1



Max profit:	38976		x1	x2	x3	x4			
			80	65	85.75	73.75			
how many ha of each crop to plant to maximize profit:			219.2	0	250	0	the amount of resource spent		the amount of resource available
subject to these constraints:			x1	x2	x3	x4	LHS		RHS
	total area	area 1	1	1	1	1	469.230769	<=	1500
	area restriction for species x1	area 2	1				219.230769	<=	250
	area restriction for species x2	area 3		1			0	<=	250
	area restriction for species x3	area 4			1		250	<=	250
	area restriction for species x4	area 5				1	0	<=	250
	hours of family labour	labour	3.25	3	3.15	3.3	1500	<=	1500
	cost per ha	cost	250	200	245	230	116057.692	<=	120000

Allows answering to questions such as:

1. If the objective function changes, how does the solution change?
2. If resources available change, how does the solution change?

x1	x2	x3	x4
80	65	85.75	73.75
219.2	0	250	0

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$H$13	how many ha of each crop to plant to maximize profit: x1	219.2307692	0	80	8.472222222	7.367424242
$I$13	how many ha of each crop to plant to maximize profit: x2	0	-8.846153846	65	8.846153846	1E+30
$J$13	how many ha of each crop to plant to maximize profit: x3	250	0	85.75	1E+30	8.211538462
$K$13	how many ha of each crop to plant to maximize profit: x4	0	-7.480769231	73.75	7.480769231	1E+30

Resources spent

Total amount of resources originally available

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$L$16	area 1 LHS	469.2307692	0	1500	1E+30	1030.769231
$L$17	area 2 LHS	219.2307692	0	250	1E+30	30.76923077
$L$18	area 3 LHS	0	0	250	1E+30	250
$L$19	area 4 LHS	250	8.211538462	250	226.1904762	31.74603175
$L$20	area 5 LHS	0	0	250	1E+30	250
$L$21	labour LHS	1500	24.61538462	1500	51.25	712.5
$L$22	cost LHS	116057.6923	0	120000	1E+30	3942.307692

the amount of resource available
RHS
1500
250
250
250
250
1500
120000

Answer Report 1 | **Sensitivity Report 1** | Limits Report 1 | Sheet1

Sensitivity Report

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53

Allows answering to questions such as:

1. **If the objective function changes, how does the solution change?**

$$\text{Maximize } Z = 80x_1 + 65x_2 + 85.75x_3 + 73.75x_4$$

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$H$13	how many ha of each crop to plant to maximize profit: x1	219.2307692	0	80	8.472222222	7.367424242
$I$13	how many ha of each crop to plant to maximize profit: x2	0	-8.846153846	65	8.846153846	1E+30
$J$13	how many ha of each crop to plant to maximize profit: x3	250	0	85.75	1E+30	8.211538462
$K$13	how many ha of each crop to plant to maximize profit: x4	0	-7.480769231	73.75	7.480769231	1E+30

First, let us analyze the ***Variable Cells*** part of the table:

- The Final Value = ***Optimal Solution***, thus replacing the final values (**x1, X2, X3, X4**) = (**219.23, 0, 250, 0**) in the objective function leads to:

MAX Z = **80*****2.19.2** + **65*****0** + **85.75*****250** + **73.75*****0** = 38 976 €

This tells the farmer that to maximize profit she should plant:

219.2 ha of x1 (corn)
0 ha of x2 (sorghum)
250 ha of x3 (wheat)
0 ha of x4 (soybeans)

Answer Report 1 | **Sensitivity Report 1** | Limits Report 1 | Sheet1

Sensitivity Report

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53

Allows answering to questions such as:

1. **If the objective function changes, how does the solution change?**

$$\text{Maximize } Z = 80x_1 + 65x_2 + 85.75x_3 + 73.75x_4$$

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$H$13	how many ha of each crop to plant to maximize profit: x1	219.2307692	0	80	8.472222222	7.367424242
$I$13	how many ha of each crop to plant to maximize profit: x2	0	-8.846153846	65	8.846153846	1E+30
$J$13	how many ha of each crop to plant to maximize profit: x3	250	0	85.75	1E+30	8.211538462
$K$13	how many ha of each crop to plant to maximize profit: x4	0	-7.480769231	73.75	7.480769231	1E+30

interval	
72.6	88.5
INFINITY	73.8
77.5	INFINITY
INFINITY	81.2

First, let us analyze the ***Variable Cells*** part of the table:

- The Final Value = ***Optimal Solution***, thus replacing the final values (**x1, X2, X3, X4**) = (**219.23, 0, 250, 0**) in the objective function leads to:

MAX Z = **80*****2.19.2** + **65*****0** + **85.75*****250** + **73.75*****0** = 38 976 €

- The ***allowable increase and decrease*** show how much the ***coeff. of the objective function*** can change before the ***optimal solution*** has to be altered

If the **coeff of X1** increases up to **88.5** or drops down to **72.6** the optimal solution will hold = (**219.23, 0, 250, 0**)

MAX Z = **88.5*****2.19.2** + **65*****0** + **85.75*****250** + **73.75*****0** = 40833.3 €
MAX Z = **72.6*****2.19.2** + **65*****0** + **85.75*****250** + **73.75*****0** = 22827.7 €

Sensitivity Report

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53

Allows answering to questions such as:

1. **If the objective function changes, how does the solution change?**

$$\text{Maximize } Z = 80x_1 + 65x_2 + 85.75x_3 + 73.75x_4$$

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$H$13	how many ha of each crop to plant to maximize profit: x1	219.2307692	0	80	8.472222222	7.367424242
$I$13	how many ha of each crop to plant to maximize profit: x2	0	-8.846153846	65	8.846153846	1E+30
$J$13	how many ha of each crop to plant to maximize profit: x3	250	0	85.75	1E+30	8.211538462
$K$13	how many ha of each crop to plant to maximize profit: x4	0	-7.480769231	73.75	7.480769231	1E+30

First, let us analyze the ***Variable Cells*** part of the table:

- The Final Value = ***Optimal Solution***, thus replacing the final values (**x1, X2, X3, X4**) = (**219.23, 0, 250, 0**) in the objective function leads to:

MAX Z = **80*****2.19.2** + **65*****0** + **85.75*****250** + **73.75*****0** = 38 976 €

The Reduced Cost measures the change in the objective function's value per unit increase in the decision variable's value.

The optimal solution tells the farmer:
"If you want to maximize profit DO NOT PLANT sorghum and soybeans"

What would happen if she planted 1 ha of sorghum (x2)? ***The profit would reduce to 38 967 €*** ***(38 976 - 8.85)***
What would happen if she planted 1 ha of soybeans (x4)? ***The profit would reduce to 38 968.5 €*** ***(38 976 – 7.48)***

Question 2.

4. By how much should sorghum's current profit per acre increase in order for the optimal solution to change? Sorghum's current profit per acre decrease would change the optimal solution?

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease		
$H$13	how many ha of each crop to plant to maximize profit: x1	219.2307692	0	80	8.472222222	7.367424242	72.6	88.5
$I$13	how many ha of each crop to plant to maximize profit: x2	0	-8.846153846	65	8.846153846	1E+30	*INFINITY*	73.8

Sorghum profit ⇔ coeficiente of x2 (set to 65)
How much can it increase to change the optimal solution?

If it increases up to the current value + the the allowable increase (73.8) the optimal solution holds

if the new value > 65+ 8.846 (the allowable increase) we'd be outsider the range (73.8) and the optimal solution would NOT hold

The profit can drop to zero that the solution will hold

APPLIED OPERATIONAL RESEARCH

Question 2.

Test - 25 May 2016

A farmer has the following resource endowments: 500 acres of land, 1500 hours of family labour and 120000 € of capital investment. She can use these resources to grow the following crops: corn, sorghum, wheat and soybeans. Any crop should not occupy more than 250 acres. Assume that the farmer works to maximize profit (revenue minus costs) from the production of these crops. She expects the following in terms of prices, crop yields, costs and labor requirements.

Crop	Price (€/bushel)	Yield (bushel/acre)	Cost (€/acre)	Labor Requirement (hours/acre)
Corn	2.75	120	250	3.25
Sorghum	2.65	100	200	3.00
Wheat	3.15	105	245	3.15
Soybeans	6.75	45	230	3.30

1. Formulate the problem as a linear program.
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?
3. Which constraints are binding? How do you interpret each binding constraint?
4. By how much should sorghum's current profit per acre increase in order for the optimal solution to change? Sorghum's current profit per acre decrease would change the optimal solution?
5. What is the shadow price for each constraint? How do you interpret this value?

Sensitivity Report

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53

Allows answering to questions such as:

1. If the objective function changes, how does the solution change?
2. **If resources available change, how does the solution change?**

Resources spent

Total amount of resources originally available

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease	interval	
$L$16	area 1 LHS	469.2307692	0	1500	1E+30	1030.769231	469.2	INFINITY
$L$17	area 2 LHS	219.2307692	0	250	1E+30	30.76923077	219.2	INFINITY
$L$18	area 3 LHS	0	0	250	1E+30	250	0.0	INFINITY
$L$19	area 4 LHS	250	8.211538462	250	226.1904762	31.74603175	218.3	476.2
$L$20	area 5 LHS	0	0	250	1E+30	250	0.0	INFINITY
$L$21	labour LHS	1500	24.61538462	1500	51.25	712.5	787.5	1551.3
$L$22	cost LHS	116057.6923	0	120000	1E+30	3942.307692	116057.7	INFINITY

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Sheet1

The Shadow Price measures the change in the objective function's value per unit increase in the constraint's bound.

Resources fully spent lead to **shadow price > zero**

Changes to the RHS of the constraints (*Total amount of resources originally available*):

- *if **within** the intervals set by the allowable decrease and increase **will not change the optimal solution** (but will affect the objective function value!)*
- *If **outside** the intervals set by the allowable decrease and increase **will change the optimal solution and the objective function value***

Sensitivity Report

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53

Allows answering to questions such as:

1. If the objective function changes, how does the solution change?
2. **If resources available change, how does the solution change?**

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease	interval	
$L$16	area 1 LHS	469.2307692	0	1500	1E+30	1030.769231	469.2	INFINITY
$L$17	area 2 LHS	219.2307692	0	250	1E+30	30.76923077	219.2	INFINITY
$L$18	area 3 LHS	0	0	250	1E+30	250	0.0	INFINITY
$L$19	area 4 LHS	250	8.211538462	250	226.1904762	31.74603175	218.3	476.2
$L$20	area 5 LHS	0	0	250	1E+30	250	0.0	INFINITY
$L$21	labour LHS	1500	24.61538462	1500	51.25	712.5	787.5	1551.3
$L$22	cost LHS	116057.6923	0	120000	1E+30	3942.307692	116057.7	INFINITY

Answer Report 1 | **Sensitivity Report 1** | Limits Report 1 | Sheet1

Constraints with a **shadow price = zero** are **not worth changing** because it will not have any impact on the objective function value

Changes on the RHS of constraints **within** the interval with a **shadow price** > **zero** will have impact on the objective function value. How much?

If the **area available to plant wheat** (constraint 4) **increases** in:

1 unit : 250 to 251 => Z_new = 38 976 € + 1 * **8.21** = 38 984
2 units: 250 to 252 => Z_new = 38 976 € + 2 * **8.21** = 38 992
226 units: 250 to **476** => Z_new = 38 976 € +**226** * **8.21** = 40 832

The same exercise can be achieved considering decreases in the RHS of constraint 4 of 31 units

Sensitivity Report

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53

Allows answering to questions such as:

1. If the objective function changes, how does the solution change?
2. **If resources available change, how does the solution change?**

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease	interval	
$L$16	area 1 LHS	469.2307692	0	1500	1E+30	1030.769231	469.2	INFINITY
$L$17	area 2 LHS	219.2307692	0	250	1E+30	30.76923077	219.2	INFINITY
$L$18	area 3 LHS	0	0	250	1E+30	250	0.0	INFINITY
$L$19	area 4 LHS	250	8.211538462	250	226.1904762	31.74603175	218.3	476.2
$L$20	area 5 LHS	0	0	250	1E+30	250	0.0	INFINITY
$L$21	labour LHS	1500	24.61538462	1500	51.25	712.5	787.5	1551.3
$L$22	cost LHS	116057.6923	0	120000	1E+30	3942.307692	116057.7	INFINITY

Answer Report 1 | **Sensitivity Report 1** | Limits Report 1 | Sheet1

Constraints with a **shadow price = zero** are **not worth changing** because it will not have any impact on the objective function value

Changes on the RHS of constraints **within** the interval with a **shadow price > zero** will have impact on the objective function value. How much?

If the **family labour time available for agriculture** (constraint 6) **decreases** in:

1 unit : 1500 to 1499 => Z_new = 38 976 € - 1 * **24.62** = 38 951
2 units: 1500 to 1498 => Z_new = 38 976 € - 2 * **24.62** = 38 927
712.5 units: 1500 to **1449** => Z_new = 38 976 € - **712.5** * **24.62** = 21 438

The same exercise can be achieved considering increases in the RHS of constraint 6 of 51 units

Sensitivity Report

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [Book2]Sheet1
Report Created: 25/02/2025 12:17:53

Allows answering to questions such as:

1. If the objective function changes, how does the solution change?
2. **If resources available change, how does the solution change?**

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease	interval	
$L$16	area 1 LHS	469.2307692	0	1500	1E+30	1030.769231	469.2	INFINITY
$L$17	area 2 LHS	219.2307692	0	250	1E+30	30.76923077	219.2	INFINITY
$L$18	area 3 LHS	0	0	250	1E+30	250	0.0	INFINITY
$L$19	area 4 LHS	250	8.211538462	250	226.1904762	31.74603175	218.3	476.2
$L$20	area 5 LHS	0	0	250	1E+30	250	0.0	INFINITY
$L$21	labour LHS	1500	24.61538462	1500	51.25	712.5	787.5	1551.3
$L$22	cost LHS	116057.6923	0	120000	1E+30	3942.307692	116057.7	INFINITY

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Sheet1

Constraints with a **shadow price = zero** are **not worth changing** because it will not have any impact on the objective function value

The impact of changes on the RHS of constraints that fall **outside** the interval can only be determined by solving the problem again!

APPLIED OPERATIONAL RESEARCH

Question 2.

Test - 25 May 2016

A farmer has the following resource endowments: 500 acres of land, 1500 hours of family labour and 120000 € of capital investment. She can use these resources to grow the following crops: corn, sorghum, wheat and soybeans. Any crop should not occupy more than 250 acres. Assume that the farmer works to maximize profit (revenue minus costs) from the production of these crops. She expects the following in terms of prices, crop yields, costs and labor requirements.

Crop	Price (€/bushel)	Yield (bushel/acre)	Cost (€/acre)	Labor Requirement (hours/acre)
Corn	2.75	120	250	3.25
Sorghum	2.65	100	200	3.00
Wheat	3.15	105	245	3.15
Soybeans	6.75	45	230	3.30

1. Formulate the problem as a linear program.
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?
3. Which constraints are binding? How do you interpret each binding constraint?
4. By how much should sorghum's current profit per acre increase in order for the optimal solution to change? Sorghum's current profit per acre decrease would change the optimal solution?
5. What is the shadow price for each constraint? How do you interpret this value?

The Shadow Price is the impact that one unitary change in the RHS of any given constraint will have in the objective function value. This is only true as long as changes on the RHS of constraints remain within the interval determined by the allowable increases and decreases

APPLIED OPERATIONAL RESEARCH

Question 2.

Test - 25 May 2016

A farmer has the following resource endowments: 500 acres of land, 1500 hours of family labour and 120000 € of capital investment. She can use these resources to grow the following crops: corn, sorghum, wheat and soybeans. Any crop should not occupy more than 250 acres. Assume that the farmer works to maximize profit (revenue minus costs) from the production of these crops. She expects the following in terms of prices, crop yields, costs and labor requirements.

Crop	Price (€/bushel)	Yield (bushel/acre)	Cost (€/acre)	Labor Requirement (hours/acre)
Corn	2.75	120	250	3.25
Sorghum	2.65	100	200	3.00
Wheat	3.15	105	245	3.15
Soybeans	6.75	45	230	3.30

1. Formulate the problem as a linear program.
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?
3. Which constraints are binding? How do you interpret each binding constraint?
4. By how much should sorghum's current profit per acre increase in order for the optimal solution to change? Sorghum's current profit per acre decrease would change the optimal solution?
5. What is the shadow price for each constraint? How do you interpret this value?
6. What is the range of feasibility for the maximum number of hours of family labour with respect to the shadow price? How do you interpret this range?

Question 2.

6. What is the range of feasibility for the maximum number of hours of family labour with respect to the shadow price? How do you interpret this range?

The range of feasibility with respect to the maximum number of hours sets the upper limit at 1551.3 considering increases in labour time that can reach a maximum of 51.25 hours with a immediate consequence in the objective function value. Thus, an increase of 51.25 : from 1500 to **1551.25** =>

Z_new = 38 976 € + **51.25** * **24.62** = 40 238 € (*profit increases, original values 38 976 €*)

26	$L$20	area 5 LHS	0	0	250	1E+30	250	0.0	INFINITY
27	$L$21	labour LHS	1500	24.61538462	1500	51.25	712.5	787.5	1551.3
28	$L$22	cost LHS	116057.6923	0	120000	1E+30	3942.307692	116057.7	INFINITY

However, na increase of 52 hours would already fall outsider the range of feasibility making impossible to use the shadow price to determine the impact on the objective function and forcing the problema to be solved again.

APPLIED OPERATIONAL RESEARCH

Question 2.

Test - 25 May 2016

A farmer has the following resource endowments: 500 acres of land, 1500 hours of family labour and 120000 € of capital investment. She can use these resources to grow the following crops: corn, sorghum, wheat and soybeans. Any crop should not occupy more than 250 acres. Assume that the farmer works to maximize profit (revenue minus costs) from the production of these crops. She expects the following in terms of prices, crop yields, costs and labor requirements.

Crop	Price (€/bushel)	Yield (bushel/acre)	Cost (€/acre)	Labor Requirement (hours/acre)
Corn	2.75	120	250	3.25
Sorghum	2.65	100	200	3.00
Wheat	3.15	105	245	3.15
Soybeans	6.75	45	230	3.30

1. Formulate the problem as a linear program.
2. Solve the problem using the Excel Solver. What is the optimal solution to the problem?
3. Which constraints are binding? How do you interpret each binding constraint?
4. By how much should sorghum's current profit per acre increase in order for the optimal solution to change? Sorghum's current profit per acre decrease would change the optimal solution?
5. What is the shadow price for each constraint? How do you interpret this value?
6. What is the range of feasibility for the maximum number of hours of family labour with respect to the shadow price? How do you interpret this range?
7. How much the profit would change if one acre of soybeans were forced into the current optimal solution?

Question 2.

7. How much the profit would change if one acre of soybeans were forced into the current optimal solution?

Imposing the plantation of 1 ha of soybeans will have a negative impact of 7.48 € in the final profit value. Thus, the increase of x4 frm 0 to 1 ha

Z_new = 38 976 € - **7.48** = ***38 968.5*** € (*profit decreases, original values 38 976 €*)

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$H$13	how many ha of each crop to plant to maximize profit: x1	219.2307692	0	80	8.472222222	7.367424242
$I$13	how many ha of each crop to plant to maximize profit: x2	0	-8.846153846	65	8.846153846	1E+30
$J$13	how many ha of each crop to plant to maximize profit: x3	250	0	85.75	1E+30	8.211538462
$K$13	how many ha of each crop to plant to maximize profit: x4	0	-7.480769231	73.75	7.480769231	1E+30

APPLIED OPERATIONAL RESEARCH

Question 7.

Exam - 17 June 2022

A certain university maintains a powerful mainframe computer for research use. There are four operators (two graduate students and two undergraduate students) to operate and maintain the computer, as well as to perform some programming services, from Wednesday to Friday (in the other days the computer is to be operated by staff outside the university). They all have different wage rates because of differences in their experience with computers and in their programming ability. Table 1 shows their wage rates, along with the maximum number of hours that each can work each day. Each operator is guaranteed a certain minimum number of hours per week that will maintain an adequate knowledge of the operation. This level is set arbitrarily at 7 hours per week for the graduate students (A and B) and 8 hours per week for the undergraduate students (C and D).

Operators	Wage Rate (€/hour)	Maximum Hours of Availability		
		Wednesday	Thursday	Friday
A	10.00	6	0	6
B	10.10	6	6	0
C	9.90	0	4	4
D	9.80	5	0	5

The computer facility is to be open for operation from 8 A.M. to 6 P.M. every day. The director of the computer facility wishes to determine the **number of hours she should assign to each operator on each day** in order to minimize cost.

1. Formulate a linear programming model for this problem.

2. Determine a feasible solution.

Book3 - Excel

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Get External Data | Get & Transform | Connections | Sort & Filter | Data Tools | Forecast | Outline | Analysis

=SUMPRODUCT($F$13:$M$13,F15:M15)

7			x5	nr working hours for worker C on Thursday																						
8			x6	nr working hours for worker C on Friday																						
9			x7	nr working hours for worker D on Wednesday																						
10			x8	nr working hours for worker D on Friday																						
11																										
12																										
13						10	10	10.1	10.1	9.9	9.9	9.8	9.8													
14				Min C		x1	x2	x3	x4	x5	x6	x7	x8													
15				0		0	0	0	0	0	0	0	0													
16																										
17																										
18					*day*	*W*	*F*	*W*	*T*	*T*	*F*	*W*	*F*														
19					*worker*	*A*	*A*	*B*	*B*	*C*	*C*	*D*	*D*														
20					nr hours	**x1**	**x2**	**x3**	**x4**	**x5**	**x6**	**x7**	**x8**	**LHS**		**RHS**											
21					total hours required on Wednesday	1		1				1		0	=	10											
22					total hours required on Thursday				1	1				0	=	10											
23					total hours required on Friday		1				1		1	0	=	10											
24					minimum hours required for worker A	1	1							0	>=	7											
25					minimum hours required for worker B			1	1					0	>=	7											
26					minimum hours required for worker C					1	1			0	>=	8											
27					minimum hours required for worker D							1	1	0	>=	8											
28					hours availability by worker A on Wednesday	1								0	<=	6											
29					hours availability by worker A on Friday		1							0	<=	6											
30					hours availability by worker B on Wednesday			1						0	<=	6											
31					hours availability by worker B on Thursday				1					0	<=	6											
32					hours availability by worker C on Thursday					1				0	<=	4											
33					hours availability by worker C on Friday						1			0	<=	4											
34					hours availability by worker D on Wednesday							1		0	<=	5											
35					hours availability by worker D on Friday								1	0	<=	5											
36																										

Sheet1

Solver Parameters

Set Objective: $D$15

To: Max | Min | Value Of: 0

By Changing Variable Cells: $F$15:$M$15

Subject to the Constraints:

Add | Change | Delete | Reset All | Load/Save

Make Unconstrained Variables Non-Negative

Select a Solving Method: GRG Nonlinear | Options

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Help | Solve | Close

Enter

POR 21:55 25/02/2025

Book3 - Excel

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Get External Data | Get & Transform | Connections | Sort & Filter | Data Tools | Forecast | Outline | Analysis

D15 =SUMPRODUCT($F$13:$M$13,F15:M15)

7			x5	nr working hours for worker C on Thursday																						
8			x6	nr working hours for worker C on Friday																						
9			x7	nr working hours for worker D on Wednesday																						
10			x8	nr working hours for worker D on Friday																						
11																										
12																										
13						10	10	10.1	10.1	9.9	9.9	9.8	9.8													
14				Min C		x1	x2	x3	x4	x5	x6	x7	x8													
15				0		0	0	0	0	0	0	0	0													
16																										
17																										
18					*day*	*W*	*F*	*W*	*T*	*T*	*F*	*W*	*F*														
19					*worker*	*A*	*A*	*B*	*B*	*C*	*C*	*D*	*D*														
20					nr hours	**x1**	**x2**	**x3**	**x4**	**x5**	**x6**	**x7**	**x8**	**LHS**		**RHS**											
21				total hours required on Wednesday		1		1				1		0	=	10											
22				total hours required on Thursday					1	1				0	=	10											
23				total hours required on Friday			1				1		1	0	=	10											
24				minimum hours required for worker A		1	1							0	>=	7											
25				minimum hours required for worker B				1	1					0	>=	7											
26				minimum hours required for worker C						1	1			0	>=	8											
27				minimum hours required for worker D								1	1	0	>=	8											
28				hours availability by worker A on Wednesday		1								0	<=	6											
29				hours availability by worker A on Friday			1							0	<=	6											
30				hours availability by worker B on Wednesday				1						0	<=	6											
31				hours availability by worker B on Thursday					1					0	<=	6											
32				hours availability by worker C on Thursday						1				0	<=	4											
33				hours availability by worker C on Friday							1			0	<=	4											
34				hours availability by worker D on Wednesday								1		0	<=	5											
35				hours availability by worker D on Friday									1	0	<=	5											
36																										

Solver Parameters

Set Objective: $D$15

To: Max Min Value Of: 0

By Changing Variable Cells: $F$15:$M$15

Subject to the Constraints: $N$21:$N$23 = $P$21:$P$23

Add | Change | Delete | Reset All | Load/Save

Make Unconstrained Variables Non-Negative

Select a Solving Method: GRG Nonlinear | Options

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Help | Solve | Close

Sheet1

Point

POR 21:56 25/02/2025

Book3 - Excel

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Get External Data | Get & Transform | Connections | Sort & Filter | Data Tools | Forecast | Outline | Analysis

D15 =SUMPRODUCT($F$13:$M$13,F15:M15)

7			x5	nr working hours for worker C on Thursday																						
8			x6	nr working hours for worker C on Friday																						
9			x7	nr working hours for worker D on Wednesday																						
10			x8	nr working hours for worker D on Friday																						
11																										
12																										
13						10	10	10.1	10.1	9.9	9.9	9.8	9.8													
14				Min C		x1	x2	x3	x4	x5	x6	x7	x8													
15				0		0	0	0	0	0	0	0	0													
16																										
17																										
18					*day*	*W*	*F*	*W*	*T*	*T*	*F*	*W*	*F*														
19					*worker*	*A*	*A*	*B*	*B*	*C*	*C*	*D*	*D*														
20					nr hours	**x1**	**x2**	**x3**	**x4**	**x5**	**x6**	**x7**	**x8**	**LHS**		**RHS**											
21					total hours required on Wednesday	1		1				1		0	=	10											
22					total hours required on Thursday				1	1				0	=	10											
23					total hours required on Friday		1				1		1	0	=	10											
24					minimum hours required for worker A	1	1							0	>=	7											
25					minimum hours required for worker B			1	1					0	>=	7											
26					minimum hours required for worker C					1	1			0	>=	8											
27					minimum hours required for worker D							1	1	0	>=	8											
28					hours availability by worker A on Wednesday	1								0	<=	6											
29					hours availability by worker A on Friday		1							0	<=	6											
30					hours availability by worker B on Wednesday			1						0	<=	6											
31					hours availability by worker B on Thursday				1					0	<=	6											
32					hours availability by worker C on Thursday					1				0	<=	4											
33					hours availability by worker C on Friday						1			0	<=	4											
34					hours availability by worker D on Wednesday							1		0	<=	5											
35					hours availability by worker D on Friday								1	0	<=	5											
36																										

Sheet1

Point

Solver Parameters

Set Objective: $D$15

To: Max | Min | Value Of: 0

By Changing Variable Cells: $F$15:$M$15

Subject to the Constraints:

$N$21:$N$23 = $P$21:$P$23
$N$24:$N$27 >= $P$24:$P$27

Add | Change | Delete | Reset All | Load/Save

Make Unconstrained Variables Non-Negative

Select a Solving Method: GRG Nonlinear | Options

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Help | Solve | Close

POR 21:57 25/02/2025

Book3 - Excel

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Get External Data | Get & Transform | Connections | Sort & Filter | Data Tools | Forecast | Outline | Analysis

=SUMPRODUCT($F$13:$M$13,F15:M15)

x5	nr working hours for worker C on Thursday		
x6	nr working hours for worker C on Friday		
x7	nr working hours for worker D on Wednesday		
x8	nr working hours for worker D on Friday		

														RHS	
total hours r													=	10	
total hour													=	10	
total ho													=	10	
minimum hours													>=	7	
minimum hours													>=	7	
minimum hours													>=	8	
minimum hours													>=	8	
hours availability by w													<=	6	
hours availability													<=	6	
hours availability by w													<=	6	
hours availability by													<=	6	
hours availability by													<=	4	
hours availability													<=	4	
hours availability by w													<=	5	
hours availability by worker D on Friday											1	0	<=	5	

Solver Results

Solver found a solution. All Constraints and optimality conditions are satisfied.

Keep Solver Solution

Restore Original Values

Reports: Answer, Sensitivity, Limits

Return to Solver Parameters Dialog

Outline Reports

OK | Cancel | Save Scenario...

Solver found a solution. All Constraints and optimality conditions are satisfied.

When the GRG engine is used, Solver has found at least a local optimal solution. When Simplex LP is used, this means Solver has found a global optimal solution.

Solver Parameters

Set Objective: $D$15

To: Max | Min | Value Of: 0

By Changing Variable Cells: $F$15:$M$15

Subject to the Constraints:

$N$21:$N$23 = $P$21:$P$23
$N$24:$N$27 >= $P$24:$P$27
$N$28:$N$35 <= $P$28:$P$35

Add | Change | Delete | Reset All | Load/Save

Make Unconstrained Variables Non-Negative

Select a Solving Method: Simplex LP | Options

Solving Method

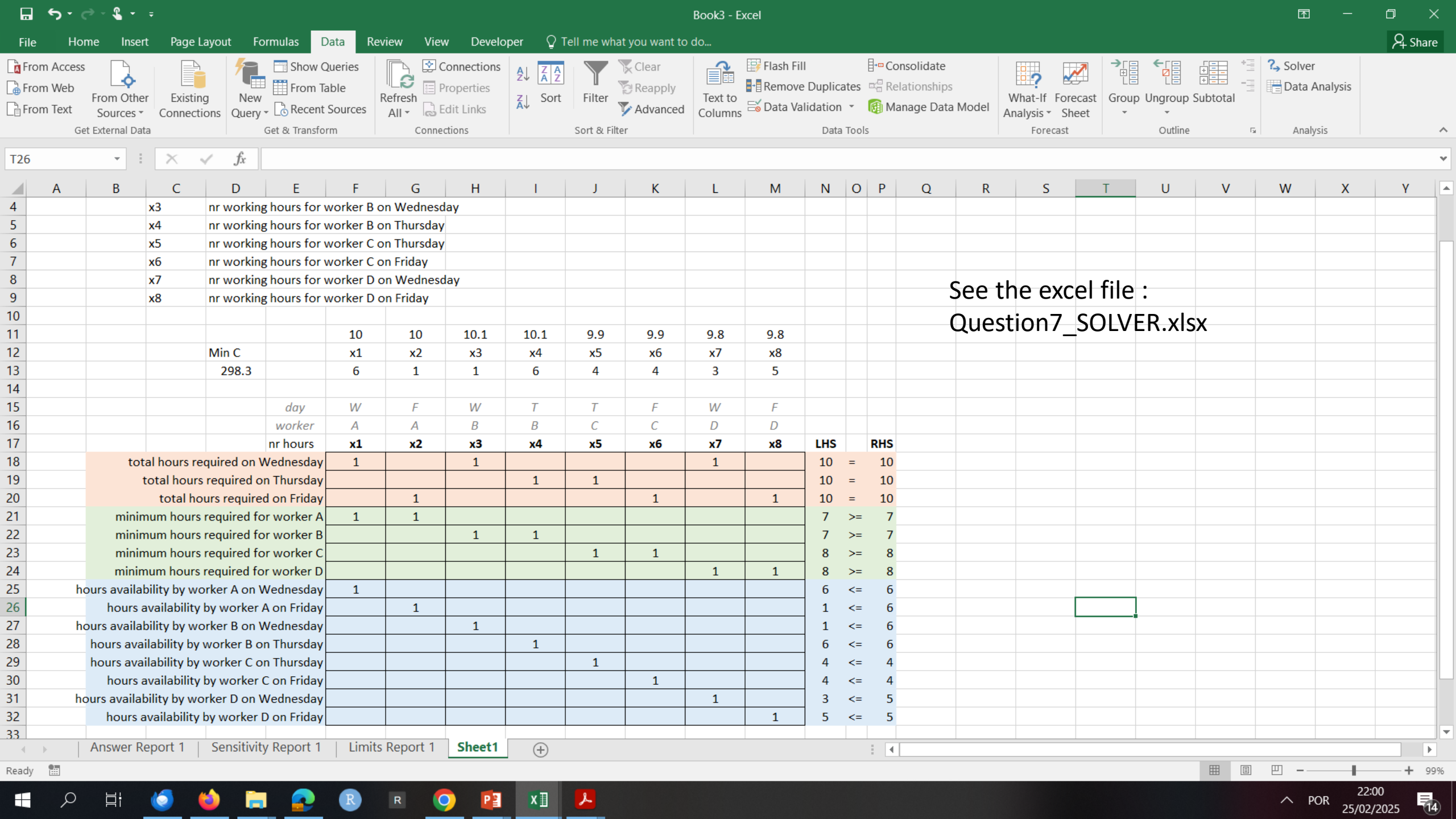
Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Help | Solve | Close

Sheet1

Ready

POR 21:58 25/02/2025



Book3 - Excel

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From Access | From Web | From Text | From Other Sources | Existing Connections | New Query | Show Queries | From Table | Recent Sources | Refresh All | Connections | Properties | Edit Links | Sort | Filter | Clear | Reapply | Advanced | Text to Columns | Flash Fill | Remove Duplicates | Data Validation | Consolidate | Relationships | Manage Data Model | What-If Analysis | Forecast Sheet | Group | Ungroup | Subtotal | Solver | Data Analysis

Get External Data | Get & Transform | Connections | Sort & Filter | Data Tools | Forecast | Outline | Analysis

T26

4			x3	nr working hours for worker B on Wednesday																					
5			x4	nr working hours for worker B on Thursday																					
6			x5	nr working hours for worker C on Thursday																					
7			x6	nr working hours for worker C on Friday																					
8			x7	nr working hours for worker D on Wednesday																					
9			x8	nr working hours for worker D on Friday																					
10																									
11						10	10	10.1	10.1	9.9	9.9	9.8	9.8												
12				Min C		x1	x2	x3	x4	x5	x6	x7	x8												
13				298.3		6	1	1	6	4	4	3	5												
14																									
15					*day*	*W*	*F*	*W*	*T*	*T*	*F*	*W*	*F*													
16					*worker*	*A*	*A*	*B*	*B*	*C*	*C*	*D*	*D*													
17					nr hours	**x1**	**x2**	**x3**	**x4**	**x5**	**x6**	**x7**	**x8**	**LHS**		**RHS**										
18				total hours required on Wednesday		1		1				1		10	=	10										
19				total hours required on Thursday					1	1				10	=	10										
20				total hours required on Friday			1				1		1	10	=	10										
21				minimum hours required for worker A		1	1							7	>=	7										
22				minimum hours required for worker B				1	1					7	>=	7										
23				minimum hours required for worker C						1	1			8	>=	8										
24				minimum hours required for worker D								1	1	8	>=	8										
25				hours availability by worker A on Wednesday		1								6	<=	6										
26				hours availability by worker A on Friday			1							1	<=	6										
27				hours availability by worker B on Wednesday				1						1	<=	6										
28				hours availability by worker B on Thursday					1					6	<=	6										
29				hours availability by worker C on Thursday						1				4	<=	4										
30				hours availability by worker C on Friday							1			4	<=	4										
31				hours availability by worker D on Wednesday								1		3	<=	5										
32				hours availability by worker D on Friday									1	5	<=	5										
33																									

See the excel file :
Question7_SOLVER.xlsx

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Sheet1

Ready

99%

POR 22:00 25/02/2025

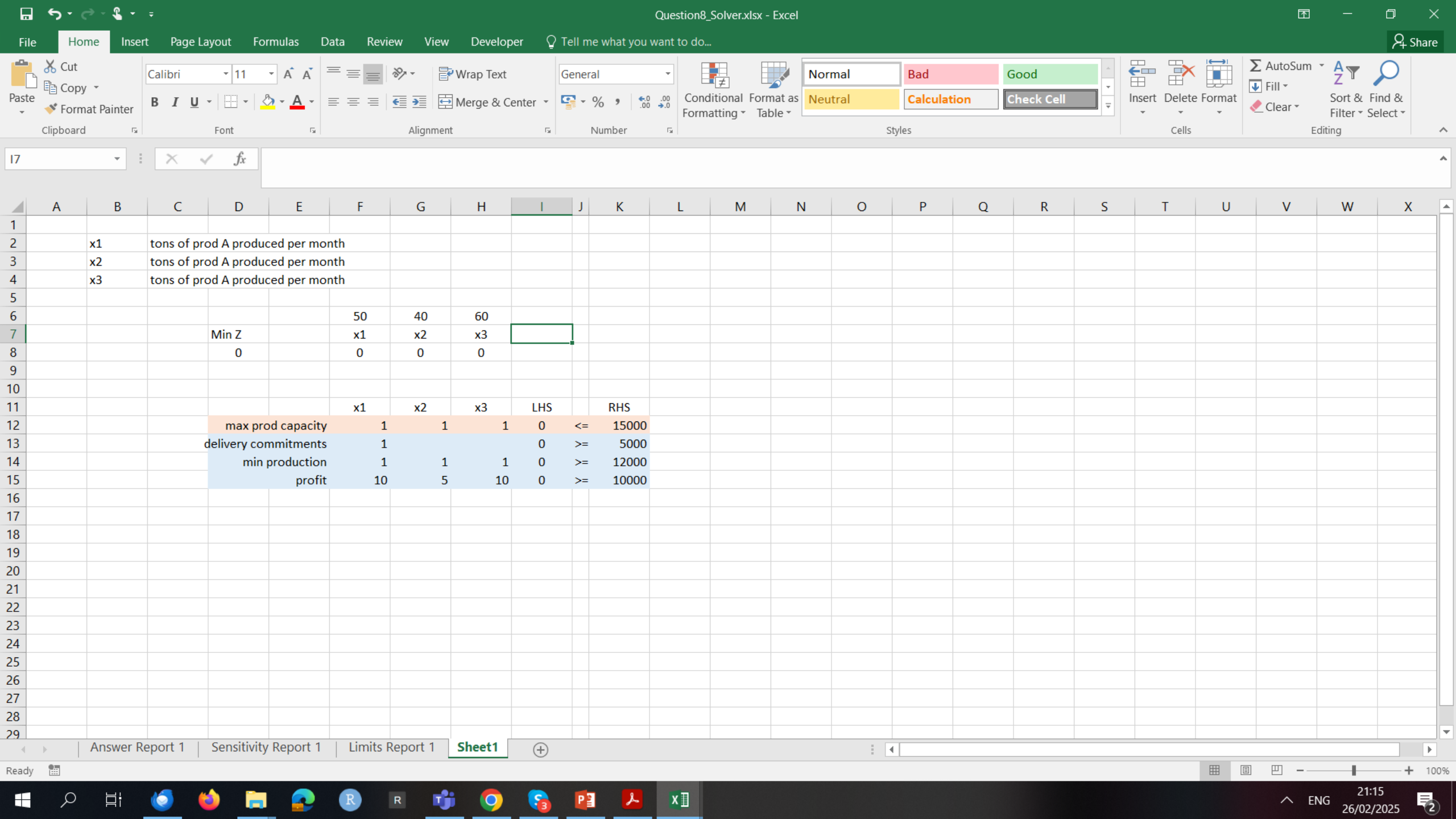
Question 8.

Exam - 30 June 2022

A company produces three types of forest products, A, B and C. Each ton of product A, B and C generates 50, 40 and 60 units of toxic waste and generate a profit of 10, 5 and 10 euros, respectively. The company has the capacity to produce up to 15 thousand tons of products per month. Commitments already made oblige the company to deliver to a certain customer 5 thousand tons of product A each month. One intends to determine the **monthly production plan** that generates the minimum amount of toxic waste with a monthly profit of at least 100 thousand euros and a monthly production of never less than 80% of the maximum production capacity of the company.

1. Formulate a linear programming model for this problem.

2. Consider that 12 thousand tons of products are produced each month, generating a profit of 100 thousand euros and that the monthly production of product A is 8 thousand tons. Indicate the quantities of products B and C produced and the amount of toxic waste generated.



Question8_Solver.xlsx - Excel

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Paste Cut Copy Format Painter | Calibri 11 | Wrap Text | General | Conditional Formatting | Format as Table | Normal Bad Good Neutral Calculation Check Cell | Insert Delete Format | AutoSum Fill Clear | Sort & Filter Find & Select

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1																								
2		x1	tons of prod A produced per month																					
3		x2	tons of prod A produced per month																					
4		x3	tons of prod A produced per month																					
5																								
6						50	40	60																
7				Min Z		x1	x2	x3																
8				0		0	0	0																
9																								
10																								
11						x1	x2	x3	LHS		RHS													
12				max prod capacity		1	1	1	0	<=	15000													
13				delivery commitments		1			0	>=	5000													
14				min production		1	1	1	0	>=	12000													
15				profit		10	5	10	0	>=	10000													
16																								
17																								
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Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Sheet1

Ready 100%

ENG 21:15 26/02/2025

Question8_Solver.xlsx - Excel

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1																								
2		x1	tons of prod A produced per month																					
3		x2	tons of prod A produced per month																					
4		x3	tons of prod A produced per month																					
5																								
6						50	40	60																
7				Min Z		x1	x2	x3																
8				530000		5000	7000	0																
9																								
10																								
11						x1	x2	x3	LHS		RHS													
12				max prod capacity		1	1	1	12000	<=	15000													
13				delivery commitments		1			5000	>=	5000													
14				min production		1	1	1	12000	>=	12000													
15				profit		10	5	10	85000	>=	10000													
16																								
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See the excel file :
Question8_SOLVER.xlsx

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Sheet1

Ready

ENG 21:13 26/02/2025

Question 9.

Test - 29 March 2023

A company transports a certain product from the warehouses A and B to the sales centers P and Q. The amounts of product in A and B are 35 and 50 tons, respectively. The demands for P and Q are 40 and 30 tons, respectively. The cost, in euros, of transporting 1 ton of product from each warehouse to each sale center is indicated in the following table.

	P	Q
A	12	20
B	15	17

The company wants to establish a supply plan that meets the minimum cost. Formulate the problem in linear programming.

Question9_Solver.xlsx - Excel

xAP	nr of tons of prod transported from warehouse A to sales P
xAQ	nr of tons of prod transported from warehouse A to sales Q
xBP	nr of tons of prod transported from warehouse B to sales P
xBQ	nr of tons of prod transported from warehouse B to sales Q

		sales		amount of prod stored
		P	Q	
warehouse	A	12	20	35
	B	15	17	50
demand for product at		40	30	

12	20	15	17
xAP	xAQ	xBP	xBQ
35	0	5	30

Min C

1005

Positive Shadow Price: The objective function value will increase

Negative Shadow Price: The objective function value will decrease

	xAP	xAQ	xBP	xBQ	LHS		RHS			shadow price
stock constraints at warehouse A	1	1			35	<=	35	0	*binding constraint*	-3
stock constraints at warehouse B			1	1	35	<=	50	15		0
demand constraints of shop P	1		1		40	=	40	0	*binding constraint*	15
demand constraints of shop Q		1		1	30	=	30	0	*binding constraint*	17

if one additional ton of product is transported, it will hgave a cost of 1005-3=1002

if I increase the demand in shop P in 1 ton (from 30 to 31) since no product is transpoted from warehouse A to shopQ and the transportation cost of B to Shop Q is 17, the cost would raise to 1005+17

optimal solution All the 35 tons of product at warehouse A are transported to sales P
no product is transported from warehouse A to sales Q
5 tons of prod are transported from wareahouse B to sales P
35 tons of prod are transported from wareahouse B to sales Q
resulting in a minimum cost of 1005

(xAP, xAQ, xBP, xBQ) (35, 0, 5, 30)

See the excel file : Question9_SOLVER.xlsx

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Question9

Question 11.

Exam - 16 June 2023

A student on a tight budget wishes to plan a daily diet which will minimize his food expenditure while maintaining minimum nutritional requirements, according to the Recommended Daily Allowance (RDA). The student wants to plan his menu fom the following goods: hamburgers, hot dogs, salad, chicken, pizza, carrots and cookies. The dietary information and cost of these foods is as follows:

Nutrient	Hamburger	Hot dog	Salad	Chicken	Pizza	Carrots	Cookies	RDA
Calories (cal/kg)	4400	4200	1000	1400	5000	600	5200	5000 cal
Calcium (mg/kg)	200	400	800	600	950	800	300	160 mg
Protein (mg/kg)	100	140	40	90	70	50	20	50 mg
Iron (mg/kg)	50	30	60	20	10	30	40	30 mg
Cost (€/kg)	5.0	4.0	3.5	6.0	10.0	4.5	7.0	

Furthermore, assume that the student wants to eat 125 grams of cookies each day and will eat at most 250 grams of carrots per day.

Formulate the problem as a linear program and indicate a feasible daily diet with the corresponding cost.

Question11_Solver.xlsx - Excel

Nutrient		Hamburge	Hotdog	Salad	Chicken	Pizza	Carrots	Cookies	RDA	
Calories	(cal/kg)	4400	4200	1000	1400	5000	600	5200	5000	cal
Calcium	(mg/kg)	200	400	800	600	950	800	300	160	mg
Protein	(mg/kg)	100	140	40	90	70	50	20	50	mg
Iron	(mg/kg)	50	30	60	20	10	30	40	30	mg
Cost	(e/kg)	5	4	3.5	6	10	4.5	7		

assume that the student wants to eat 125 grams of cookies each day and will eat at most 250 grams of carrots per day.

		5	4	3.5	6	10	4.5	7					
	Min C	x1	x2	x3	x4	x5	x6	x7					
	5.017857	0	1.035714	0	0	0	0	0.125	diet composition		dietary daily requirements		
		x1	x2	x3	x4	x5	x6	x7	LHS		RHS		
calories requirements		4400	4200	1000	1400	5000	600	5200	5000	>=	5000		
calcium requirements		200	400	800	600	950	800	300	452	>=	160		
protein requirements		100	140	40	90	70	50	20	148	>=	50		
iron requirements		50	30	60	20	10	30	40	36	>=	30		
daily consumption of cookies								1	0.125	>=	0.125		
daily consumption of carrotts							1		0	<=	0.25		

x1	Hamburger	0.809524
x2	Hotdog	0
x3	Salad	2.547619
x4	Chicken	4.666667
x5	Pizza	5.238095
x6	Carrots	3.928571
x7	Cookies	0

Reduced Cost		
0	daily requirement for calories is met	Binding
-291.786	calcium requirements above the daily need	Not Binding
-97.5	protein requirements above the daily need	Not Binding
-6.07143	iron requirements above the daily need	Not Binding
0	daily comsumption of cookies is met	Binding
0.25	luckily no carrots are eaten	Not Binding

if the student decided to change his diet, changing to hamburgers would result in a smaller cost increase than if he went for any other option going for;

Hamburge	instesad of hotdog would increase the cost:	5.827381
Salad	instesad of hotdog would increase the cost:	7.565476
Carrots	instesad of hotdog would increase the cost:	8.946429
Chicken	instesad of hotdog would increase the cost:	9.684524
Pizza	instesad of hotdog would increase the cost:	10.25595

thus if the calcium amount increases this will not have an impact on the objective

Optimum solution:

to meet the student requirements at a minimum cost he can simply eat 1.03 kg of hotdogs and 125 g of cookies

See the excel file : Question11_SOLVER.xlsx

Answer Report 1 | Sensitivity Report 1 | Limits Report 1 | Question11

Ready