Operations research

Bryan Jiménez -
Patrick Maynard -
Dario Monestel -

Project 5: Linear Programming Problems
Second Semester 2018

18 October

Index

Problem 1

Shale Oil, located on the island of Aruba, has a capacity of 600,000 barrels of crude oil per day. The final products from the refinery include two types of unleaded gasoline ; regular and premium. The refining process encompasses four stages :

(1) The pure crude flows through a distillation tower that produces a feedstock.
(2) The feedstock output breaks up into two paths ; the first path involves feedstock flowing into a cracker unit that refines the mixture into a gasoline stock. The second path has a portion of the feedstock flowing into the blender unit.
(3) The gasoline stock (from the cracker unit) feeds into the blender.
(4) The blender unit produces the final product, regular or premium gasoline.

Problem 1

cont

Both the regular and premium gasoline can be produced from either the feedstock or the gasoline stock during the blending process, although at different production costs. The company estimates that the net profit per barrel of regular gasoline is 6.20 $ from feedstock and 8.80 $ from gasoline stock. The corresponding profit values for the premium are 11.40 $ from the feedstock and 10.30 $ from the gasoline stock. According to design specifications, it takes five barrels of crude oil to produce one barrel of feedstock. The cracker units cannot use more than 30,000 barrels of feedstock per day. All remaining feedstock is used directly in the blender unit to produce the end product gasoline. The demand limits for regular and premium gasoline are 90,000 and 60,000 barrels per day.

Problem 1 : decision variables

X1 : Regular gasoline from crude oil
X2 : Premium gasoline from crude oil
X3 : Regular gasoline coming from the disintegration
X4 : Premium gasoline from the disintegration

Problem 1 : Objective Function

Maximize

$$Z = 7.7X1 + 10.40X2 + 5.20X3 + 12.3X4$$

Problem 1 : Constraints

$X3 + X4 <= 40000$
$X1 + X3 <= 80000$
$X2 + X4 <= 50000$
$5X1 + 5X2 + 5X3 + 5X4 <= 600000$
$X1,X2,X3,X4 >= 0$

Problem 1 : Full Model

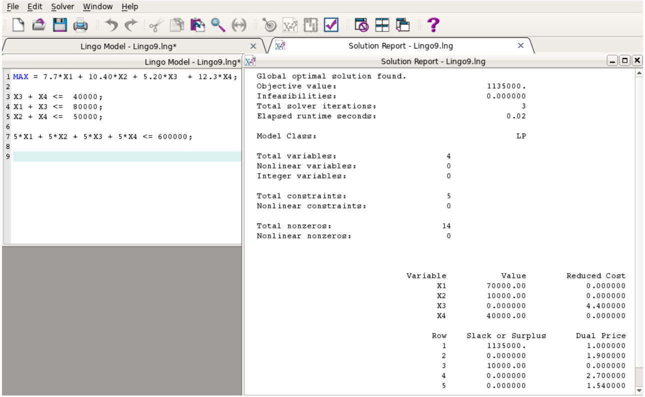
Maximize

$$Z = 7.7X1 + 10.40X2 + 5.20X3 + 12.3X4$$

subject to :

$$X3 + X4 <= 40000$$
$$X1 + X3 <= 80000$$
$$X2 + X4 <= 50000$$
$$5X1 + 5X2 + 5X3 + 5X4 <= 600000$$
$$X1,X2,X3,X4 >= 0$$

Problem 1 : Solution with Lingo



Problem 1 : Final Solution

$X1 = 70000$
$X2 = 10000$
$X3 = 0$
$X4 = 40000$
$Z = 1135000$

Index

Problem 2

Hawaii Sugar Company produces brown sugar, processed sugar (white), powdered sugar and molasses with sugar cane syrup. The company buys 4000 tons of syrup a week and has a contract to deliver a minimum of 25 tons per week of each type of sugar. The production process starts with making brown sugar and molasses with the syrup. One ton of syrup produces 0.3 tons of brown sugar and 0.1 tons of molasses. Afterwards, the white sugar is made by processing brown sugar.

Problem 2

cont

It requires 0.1 tons of brown sugar to produce 0.8 tons of white sugar. Finally, powdered sugar is made from white sugar by means of a special milling process, which has 95 % conversion efficiency (1 ton of white sugar produces .95 tons of powdered sugar). The profits per ton of brown sugar, white sugar, powdered sugar and molasses are 150, 200, 230 and 35 $, respectively.

Problem 2 : decision variables

X1 = Tons brown sugar
X2 = Tons white sugar
X3 = Tons of powdered sugar
X4 = Tons molasses

Problem 2 : Objective Function

Maximize

$$Z = 150X1 + 200X2 + 230X3 + 35X4$$

Problem 2 : Constrains

$X1 >= 25$
$X2 >= 25$
$X3 >= 25$
$X4 >= 25$
$X4 <= 400$
$0.76X1 + 0.95X2 + X3 <= 912$

Problem 2 : Full Model

Maximize

Maximize

$Z = 150X1 + 200X2 + 230X3 + 35X4$

subject to :

$X1 >= 25$

$X2 >= 25$

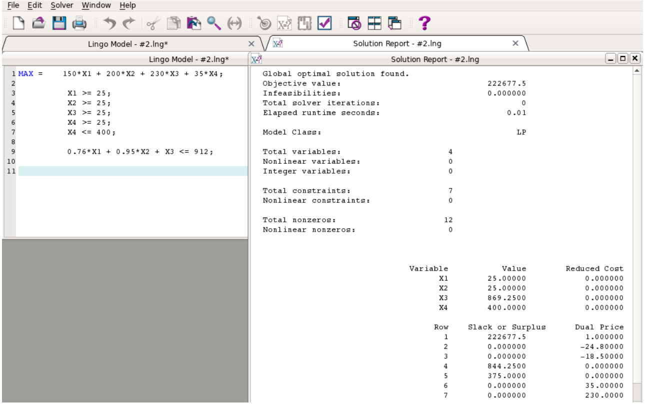
$X3 >= 25$

$X4 >= 25$

$X4 <= 400$

$0.76 * X1 + 0.95 * X2 + X3 <= 912$

Problem 2 : Solution with Lingo



Problem 2 : Final Solution

$X1 = 25$
$X2 = 25$
$X3 = 869$
$X4 = 400$
$Z = 222677.5$

Index

Problem 3

Fox Companies plans six possible construction projects during the following 4 years. The following table shows the expected revenues (at present value) and the cash disbursements for those projects. Fox is authorized to undertake any of the projects, partially or totally. A partial termination of a project will have income and proportional disbursements.

Problem 3

cont

		Tiempo de manufactura (hr) por unidad				
Máquina	*Costo por hr ($)*	*Producto 1*	*Producto 2*	*Producto 3*	*Producto 4*	*Capacidad (hr)*
1	10	2	3	4	2	500
2	5	3	2	1	2	380
Precio unitario de venta ($)		75	70	55	45	

Problem 3 : decision variables

$x1$: Amount of project 1 to undertake
$x2$: Amount of project 2 to undertake
$x3$: Amount of project 3 to undertake
$x4$: Amount of project 4 to undertake
$x5$: Amount of project 5 to undertake
$x6$: Amount of project 6 to undertake

Problem 3 : Objective Function

Maximize

$Z = 32.40x1+35.80x2+17.75x3+14.80x4+18.20x5+12.35x6$

Problem 3 : Constrains

Funds available in year 1.

$$10.5X1 + 8.3X2 + 10.2X3 + 7.2X4 + 12.3X5 + 9.2X6 <= 60$$

Funds available in year 2.

$$14.4X1 + 12.6X2 + 14.2X3 + 10.5X4 + 10.1X5 + 7.8X6 <= 70$$

Funds available in year 3.

$$2.2X1 + 9.5X2 + 5.6X3 + 7.5X4 + 8.3*X5 + 6.9X6 <= 35$$

Funds available in year 4.

$$2.4X1 + 3.1X2 + 4.2X3 + 5X4 + 6.3X5 + 5.1X6 <= 20$$

positive values

$$x1, x2, x3, x4, x5, x6 >= 0$$

Problem 3 : Full Model

Maximize

$$Z = 32.40X1 + 35.80X2 + 17.75X3 + 14.80X4 + 18.20X5 + 12.35X6$$

subject to :

$$10.5X1 + 8.3X2 + 10.2X3 + 7.2X4 + 12.3X5 + 9.2X6 <= 60$$
$$14.4X1 + 12.6X2 + 14.2X3 + 10.5X4 + 10.1X5 + 7.8X6 <= 70$$
$$2.2X1 + 9.5X2 + 5.6X3 + 7.5X4 + 8.3{*}X5 + 6.9X6 <= 35$$
$$2.4X1 + 3.1X2 + 4.2X3 + 5X4 + 6.3X5 + 5.1X6 <= 20$$

Problem 3 Solution with Lingo

File Edit Solver Window Help

Lingo Model - Lingo3.lng*

```
MAX = 32.40*X1 + 35.80*X2 + 17.75*X3 + 14.80*X4 + 18.20*X5 + 12.35*X6;

10.5*X1 + 8.3*X2 + 10.2*X3 + 7.2*X4 + 12.3*X5 + 9.2*X6 <= 60;
14.4*X1 + 12.6*X2 + 14.2*X3 + 10.5*X4 + 10.1*X5 + 7.8*X6 <= 70;
2.2*X1 + 9.5*X2 + 5.6*X3 + 7.5*X4 + 8.3*X5 + 6.9*X6 <= 35;
2.4*X1 + 3.1*X2 + 4.2*X3 + 5*X4 + 6.3*X5 + 5.1*X6 <= 20;
```

Solution Report - Lingo3.lng

```
Global optimal solution found.
Objective value:                              181.4045
Infeasibilities:                              0.000000
Total solver iterations:                             3
Elapsed runtime seconds:                          0.01

Model Class:                                        LP

Total variables:                      6
Nonlinear variables:                  0
Integer variables:                    0

Total constraints:                    5
Nonlinear constraints:                0

Total nonzeros:                      30
Nonlinear nonzeros:                   0
```

Variable	Value	Reduced Cost
X1	2.053539	0.000000
X2	3.208654	0.000000
X3	0.000000	17.57395
X4	0.000000	14.62354
X5	0.000000	11.17044
X6	0.000000	10.81414

Row	Slack or Surplus	Dual Price
1	181.4045	1.000000
2	11.80601	0.000000
3	0.000000	2.099743
4	0.000000	0.9834983
5	5.124679	0.000000

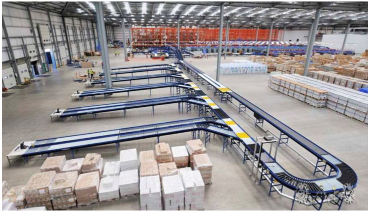
Problem 3 : Final Solution

$X1 = 2.05$
$X2 = 3.20$
$X3 = 0$
$X4 = 0$
$X5 = 0$
$X6 = 0$
$Z = 181.40$

Index

Problem 4

Manufacturing Acme received a contract to deliver housing windows for the following 6 months. The successive demands for the six periods are 100, 250, 190, 140, 220 and 110, respectively. The cost of production per window varies from month to month, depending on the costs of labor, materials and services. Acme estimates that the production cost per window, during the following 6 months, will be 50, 45, 55, 48, 52 and 50 dollars, respectively. To take advantage of fluctuations in the cost of manufacturing, Acme could choose to produce more than necessary in a given month, and save surplus units to deliver in later months. However, this will result in a storage cost of 8 $ per window and per month, evaluated with the inventory raised at the end of the month.



Problem 4 : decision variables

i = month number in this case 1,2,3,4,5,6 for 6 months
Xi = Number of units produced in month i
Ii = Units left in the end of month inventory i

Problem 4 : Objective Function

Minimize

$$Z = 50X1 + 45X2 + 55X3 + 48X4 + 52X5 + 50X6 + 8(W1 + W2 + W3 + W4 + W5 + W6)$$

Problem 4 : Constrains

$x1 - W1 = 100$
$W1 + X2 - W2 = 250$
$W2 + X3 - W3 = 190$
$W3 + X4 - W4 = 140 \cdot$
$W4 + X5 - W5 = 220$
$I5 + X6 = 110$

Problem 4 : Full Model

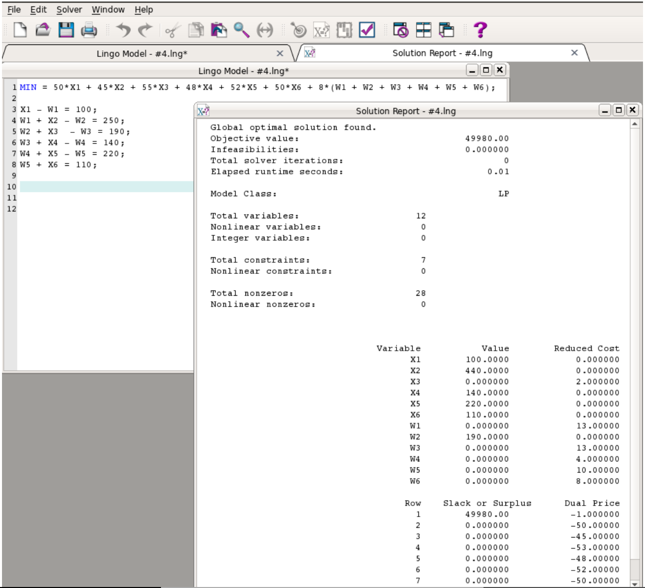
Minimize

$$Z = 50X1 + 45X2 + 55X3 + 48X4 + 52X5 + 50X6 + 8(W1 + W2 + W3 + W4 + W5 + W6)$$

subject to :

$$x1 - W1 = 100$$
$$W1 + X2 - W2 = 250$$
$$W2 + X3 - W3 = 190$$
$$W3 + X4 - W4 = 140\cdot$$
$$W4 + X5 - W5 = 220$$
$$I5 + X6 = 110$$

Problem 4 : Solution with Lingo



Problem 4 : Final Solution

$X1 = 100$
$X2 = 440$
$X3 = 0$
$X4 = 140$
$X5 = 220$
$X6 = 110$
$W1 = 100$
$W2 = 440$
$W3 = 0$
$W4 = 140$
$W5 = 220$
$W6 = 110$
$Z = 49980$

Index

Problem 5

Investor Doe has four potential opportunities to invest a total of 100,000 $. The following table provides the cash flow for four investments.

	Flujo de efectivo ($ miles) al iniciar el				
Proyecto	*Año 1*	*Año 2*	*Año 3*	*Año 4*	*Año 5*
1	−1.00	0.50	0.30	1.80	1.20
2	−1.00	0.60	0.20	1.50	1.30
3	0.00	−1.00	0.80	1.90	0.80
4	−1.00	0.40	0.60	1.80	0.95

Problem 5

cont

The information in this table can be interpreted as follows :
for project 1, 1.00 $ invested at the beginning of year 1, it will yield 0.50 $ at the beginning of year 2, 0.30 $ at the beginning of year 3, 1.80 $ at the beginning of year 4 and 1.20 $ at the beginning of year 5. The remaining elements can be interpreted in analogous A case without transactions is indicated by a 0.00 element. Juan also has the option of investing in a bank account that produces 6.5% per year. The funds accumulated in a year can be reinvested in the following years.

Problem 5 : decision variables

Xi = Dollars invested in the project i, i = 1,2,3,4
Yj = Dollars invested in the bank per year j, j= 1,2,3,4,5

Problem 5 : Objective Function

Maximize

$Z = Y5$

Problem 5 : Constrains

$X1 + X2 + X4 + Y1 <= 100\,000$
$0.5X1 + 0.6X2 - X3 + 0.4X4 + 1.065Y1 - Y2 = 0$
$0.3X1 + 0.2X2 - 0.8X3 + 0.6X4 + 1.065Y2 - Y3 = 0$
$1.8X1 + 1.5X2 - 1.9X3 + 1.8X4 + 1.065Y3 - Y4 = 0$
$1.2X1 + 1.3X2 - 0.8X3 + 0.95X4 + 1.065Y4 - Y5 = 0$
$Xi >= 0$

Problem 5 : Full Model

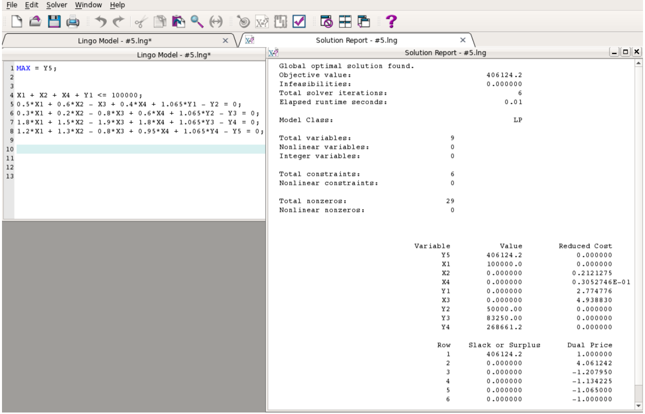
Maximize

$Z = Y5$

subject to :

$X1 + X2 + X4 + Y1 <= 100\ 000$
$0.5X1 + 0.6X2 - X3 + 0.4X4 + 1.065Y1 - Y2 = 0$
$0.3X1 + 0.2X2 - 0.8X3 + 0.6X4 + 1.065Y2 - Y3 = 0$
$1.8X1 + 1.5X2 - 1.9X3 + 1.8X4 + 1.065Y3 - Y4 = 0$
$1.2X1 + 1.3X2 - 0.8X3 + 0.95X4 + 1.065Y4 - Y5 = 0$
$Xi >= 0$

Problem 5 Solution with Lingo



Problem 5 : Final Solution

$X1 = 100000$
$X2 = 0$
$X3 = 0$
$X4 = 0$
$Y1 = 0$
$Y2 = 50000$
$Y3 = 83250$
$Y4 = 268661.2$
$Z = 406124$

Index

Problem 6

Toolco has signed a contract with AutoMate to provide their discount automotive stores with chisels and wrenches. The weekly demand of AutoMate is 1500 wrenches and 1200 chisels. Toolco's current capacity is not large enough to produce units the required units and must work overtime and possibly outsource to other tool shops.
The result is an increase in the cost of production per unit, as shown in the following table. The market restricts the wrenches to a ratio of at least 2 : 1 with the chisels.

Problem 6

cont

Herramienta	Tipo de producción	Producción semanal (unidades)	Costo unitario ($)
Llaves	Normal	0–550	2.00
	Tiempo extra	551–800	2.80
	Subcontratadas	801– ∞	3.00
Cinceles	Normal	0–620	2.10
	Tiempo extra	621–900	3.20
	Subcontratados	901– ∞	4.20

Problem 6 : decision variables

Kn : Number of keys produced in normal time
Ke : Quantity of keys produced in extra time
Ks : Number of keys by subcontract
Cn : Amount of Chisels produced in normal time
Ce : Quantity of Chisels produced in extra time
Cs : Quantity of Chisels by subcontract

Problem 6 : Objective Function

Minimize

$$Z = 2Kn + 2.8Ke + 3Ks + 2.1Cn + 3.2Ce + 4.2Cs$$

Problem 6 : Constrains

-2Kn-2Ke-2Ks+Cn+Ce+Cs >= 0 Kn + Ke + Ks >= 1500
Cn + Ce + Cs >= 1200
Kn <= 550
Cn <= 620
Kn + Ke <= 800
Cn + Ce <= 900

Problem 6 : Full Model

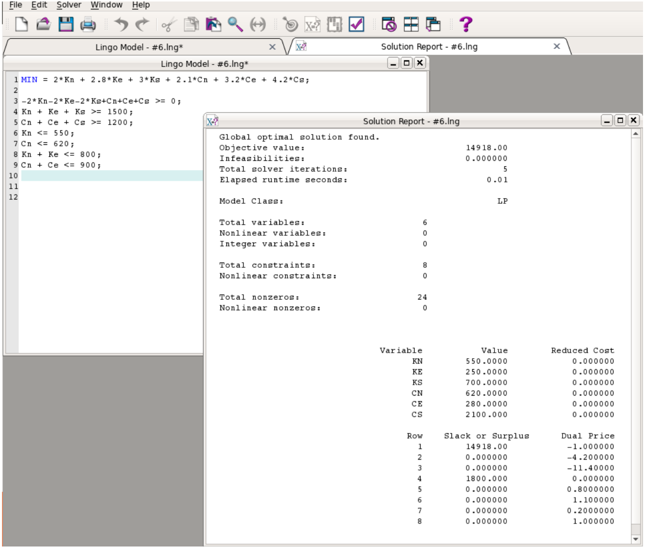
Minimize

$Z = 2Kn + 2.8Ke + 3Ks + 2.1Cn + 3.2Ce + 4.2Cs$

subject to :

-2Kn-2Ke-2Ks+Cn+Ce+Cs $>=$ 0 Kn + Ke + Ks $>=$ 1500
Cn + Ce + Cs $>=$ 1200
Kn $<=$ 550
Cn $<=$ 620
Kn + Ke $<=$ 800
Cn + Ce $<=$ 900

Problem 6 : Solution with Lingo



Problem 6 : Final Solution

$Kn = 550$
$Ke = 250$
$Ks = 700$
$Cn = 620$
$Ce = 280$
$Cs = 2100$
$Z = 14918$

Index

Problem 7

In two machines, four products are processed sequentially. The following table shows the relevant data of the problem.

		Tiempo de manufactura (hr) por unidad				
Máquina	*Costo por hr ($)*	*Producto 1*	*Producto 2*	*Producto 3*	*Producto 4*	*Capacidad (hr)*
1	10	2	3	4	2	500
2	5	3	2	1	2	380
Precio unitario de venta ($)		75	70	55	45	

P1 : Product 1
P2 : Product 2
P3 : Product 3
P4 : Product 4

Problem 7 : Objective Function

Maximize

$Z = 30P1 + 30P2 + 20P3 + 15P4$

Problem 7 : Constrains

$2P1 + 3P2 + 4P3 + 2P4 <= 500$

$3P1 + 2P2 + P3 + 2P4 <= 380$

Problem 7 : Full Model

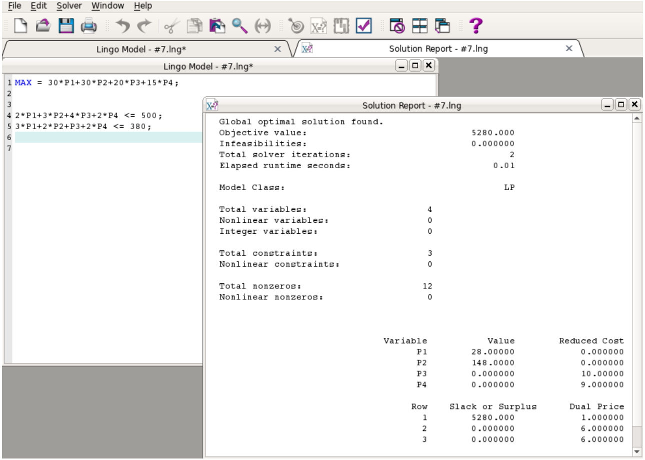
Maximize

$Z = 30P1 + 30P2 + 20P3 + 15P4$

subject to :

$2P1 + 3P2 + 4P3 + 2P4 <= 500$
$3P1 + 2P2 + P3 + 2P4 <= 380$

Problem 7 : Solution with Lingo



Problem 7 : Final Solution

$P1 = 28$
$P2 = 148$
$P3 = 0$
$P4 = 0$
$Z = 5280$

Index

Problem 8

A manufacturer produces three models, I, II and III, of a certain product, using the raw materials A and B. The following table shows the data for the problem.

	Requerida por unidad			
Materia prima	*I*	*II*	*III*	*Disponibilidad*
A	2	3	5	4000
B	4	2	7	6000
Demanda mínima	200	200	150	
Utilidad por unidad ($)	30	20	50	

The labor time for model I is double that for II and triple of III. All factory personnel can produce the equivalent of 1500 model I units. Market needs specify the 3 : 2 : 5 relationships of the productions of the three respective models.

Problem 8 : decision variables

X1 = Units to be produced from the model product I
X2 = Units to be produced of the product model II
X3 = Units to be produced of the model product III

Problem 8 : Objective Function

Maximize

$Z = 30X1 + 20X2 + 50X3$

Problem 8 : Constrains

Restriction of raw material A : $2X1 + 3X2 + 5X3 <= 4000$

Restriction of raw material B : $4X1 + 2X2 + 7X3 <= 6000$

Time restriction : $X1 + 0.5X2 + 0.33333\ X3 <= 1500$

Production ratio in models I and II : $2X1 - 3X2 = 0$

Production ratio in models II and III : $5X2 - 2X3 = 0$

Restriction of demand of the model I, II, III :

$X1, X2, x3 >= 200$
$X1, X2, X3 >= 0$

Problem 8 : Full Model

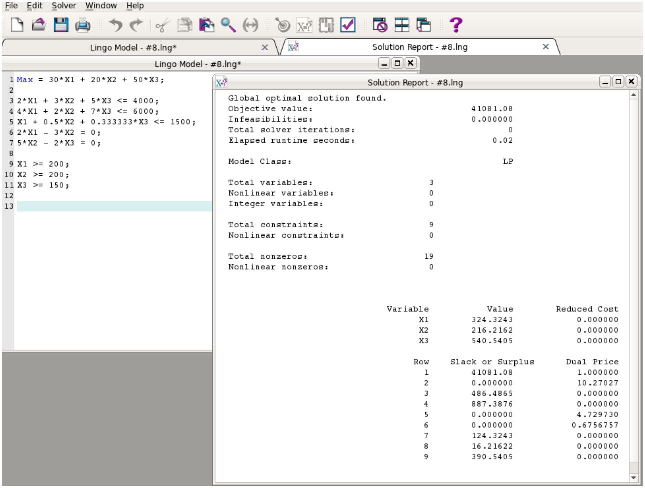
Maximize

$Z = 30X1 + 20X2 + 50X3$[1em]

subject to :

$2X1 + 3X2 + 5X3 <= 4000$
$4X1 + 2X2 + 7X3 <= 6000$
$X1 + 0.5X2 + 0.33333\ X3 <= 1500$
$2X1$ - $3X2 = 0$ $5X2$ - $2X3 = 0$ $X1,X2,x3 >= 200$
$X1,X2,X3 >= 0$

Problem 8 : Solution with Lingo



Problem 8 : Final Solution

X1 = 324
X2 = 216
X3 = 540
Z = 41081.08

Index

Problem 9

HiRise Construction can bid on two one-year projects. The quarterly cash flow (in millions of dollars) is provided in the following table for the two projects.

	Flujo de efectivo (en millones de $) al				
Proyecto	*1/1/08*	*4/1/08*	*7/1/08*	*10/1/08*	*12/31/08*
I	−1.0	−3.1	−1.5	1.8	5.0
II	−3.0	−2.5	1.5	1.8	2.8

HiRise has cash funds of 1 million at the beginning of each quarter and can borrow an amount equal to 10% of the annual nominal interest rate. This means that if the amount borrowed in quarter i is Bi then.

$$0 \leq B_i \leq 1, i = 1, 2, 3, 4.$$

Any borrowed money must be paid at the end of the quarter. The excess cash can earn a quarterly interest at a nominal annual rate of 8%. All the money accumulated at the end of a quarter is invested in the following quarter.

Problem 9 : decision variables

Pi = Fraction undertaken from project i, 1 = 1,2
Bj = Millions of dollars loaned in semester j, j = 1,2,3,4
Sj = Surplus million dollars at the beginning of semester j, j = 1,2,3,4,5

Problem 9 : Objective Function

Maximize

$Z = S5$

Problem 9 : Constrains

$P1 + 3P2 + S1 - B1 = 1$
$3.1P1 + 2.5P2 - 1.0S1 + S2 + 1.025B1 - B2 = 1$
$1.5P1 - 1.5P2 - 1.02S2 + S3 + 1.025B2 - B3 = 1$
$-1.8P1 - 1.8P2 - 1.02S3 + S4 + 1.025B3 - B4 = 1$
$-5P1 - 2.8P2 - 1.02S4 + S5 + 1.025B4 = 1$
$0 <= P1 <= 1$
$0 <= P2 <= 1$
$0 <= Bj <= 1 , j = 1,2,3,4$

Problem 9 : Full Model

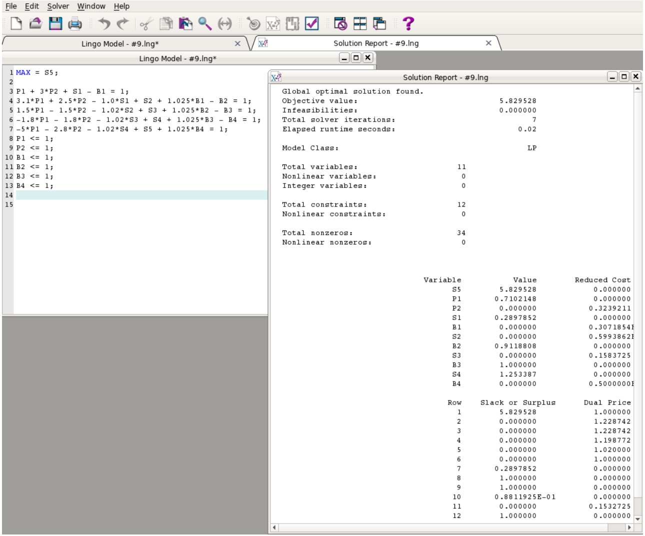
Maximize

$Z = S5$

subject to :

$P1 + 3P2 + S1 - B1 = 1$
$3.1P1 + 2.5P2 - 1.0S1 + S2 + 1.025B1 - B2 = 1$
$1.5P1 - 1.5P2 - 1.02S2 + S3 + 1.025B2 - B3 = 1$
$-1.8P1 - 1.8P2 - 1.02S3 + S4 + 1.025B3 - B4 = 1$
$-5P1 - 2.8P2 - 1.02S4 + S5 + 1.025B4 = 1$
$0 <= P1 <= 1$
$0 <= P2 <= 1$
$0 <= Bj <= 1 , j = 1,2,3,4$

Problem 9 : Solution with Lingo



Problem 9 : Final Solution

$S1 = 0.28$
$S2 = 0$
$S3 = 0$
$S4 = 1.25$
$S5 = 5.82$
$P1 = 0.81$
$P2 = 0$
$B1 = 0$
$B2 = 0.91$
$B3 = 1$
$B4 = 0$
$Z = 5.829528$

Problem 9 : Final Analysis

The solution shows that BiSi $= 0$, meaning tha you cannot borrow and also end up with surplus un any quarter. The result makes sense because the cost of borrowing 2.5% is higher than the return on surplus funds 2%

Index

Problem 10

In anticipating your child's considerable college spending, a couple has initiated an annual investment program on the day the child turned eight, which will continue until he turns 18. The couple estimates that they can invest the following amounts at the beginning of each year :

Año	1	2	3	4	5	6	7	8	9	10
Cantidad ($)	2000	2000	2500	2500	3000	3500	3500	4000	4000	5000

Problem 10

cont

To avoid unpleasant surprise, the couple chooses to invest with security in the following options :
1) Savings insured with annual return of 7.5% (profit)
2) Government bonds for 6 years, which produce 7.9% and have a current market price equal to 98% of the nominal value. (1-5) years.
3) Municipal bonds at 9 years, which produce 8.5% with a current market price of 1.02 times the nominal value. (1-2) years.

Problem 10 : decision variables

Ai = savings assured i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
BGi = Government bonds i = 1, 2, 3, 4, 5
BMi = Municipal Bonds i = 1,2

Problem 10 : Objective Function

Maximize

$$Z = 1.075A10 + 1.079Bg5 + 1.085Bm2$$

Problem 10 : Constrains

Year 1 : $2000 = A1 + 0.98Bg1 + 1.02Bm1$
Year 2 : $2000 + 1.075A1 = A2 + 0.98Bg2 + 1.02Bm2$
Year 3 : $2500 + 1.075A2 = A3 + 0.98Bg3 + 1.02Bm3$
Year 4 : $2500 + 1.075A3 = A4 + 0.98Bg4 + Bm4$
Year 5 : $3000 + 1.075A4 = A5 + 0.98Bg5 + Bm5$
Year 6 : $3500 + 1.075A5 = A6$
Year 7 : $3500 + 1.075A6 + 1.079 * 0.98Bg1 = A7$
Year 8 : $4000 + 1.075A7 + 1.079 * 0.98Bg2 = A8$
Year 9 : $4000 + 1.075A8 + 1.079 * 0.98Bg3 = A9$
Year 10 : $5000 + 1.075A9 + 1.079 * 0.98Bg4 + 1.085Bm1 = A10$

Problem 10 : Full Model

Maximize

$Z = 1.075A10 + 1.079Bg5 + 1.085Bm2$

subject to :

$2000{=}A1{+}0.98Bg1{+}1.02Bm1$
$2000{+}1.075A1{=}A2{+}0.98Bg2{+}1.02Bm2$
$2500{+}1.075A2{=}A3{+}0.98Bg3{+}1.02Bm3$
$2500{+}1.075A3{=}A4{+}0.98Bg4{+}Bm4$
$3000{+}1.075A4{=}A5{+}0.98Bg5{+}Bm5$
$3500{+}1.075A5{=}A6$
$3500 + 1.075A6 + 1.079*0.98Bg1{=}A7$
$4000{+}1.075A7{+}1.079*0.98Bg2 = A8$
$4000{+}1.075A8{+}1.079*0.98Bg3{=}A9$
$5000{+}1.075A9{+}1.079*0.98Bg4{+}1.085Bm1{=}A10$

Problem 10 : Solution with Lingo

File Edit Solver Window Help

Lingo Model - Lingo10.lng*

```
MAX = A10*1.075+Bg5*1.079+Bm2*1.085;

2000=A1+0.98*Bg1+1.02*Bm1;

2000+A1*1.075=A2+0.98*Bg2+1.02*Bm2;


2500+A2*1.075=A3+0.98*Bg3+1.02*Bm3;

2500+A3*1.075=A4+0.98*Bg4+1.02*Bm4;


3000+A4*1.075=A5+0.98*Bg5+1.02*Bm5;

3500+A5*1.075=A6;


3500 + A6*1.075 + 0.98*Bg1*1.079=A7;


4000+A7*1.075+0.98*Bg2*1.079 = A8;


4000+A8*1.075+0.98*Bg3*1.079=A9;


5000+A9*1.075+0.98*Bg4*1.079+1.02*Bm1*1.085=A10;
```

Solution Report - Lingo10.lng

```
Global optimal solution found.
Objective value:                              45858.29
Infeasibilities:                              0.000000
Total solver iterations:                             0
Elapsed runtime seconds:                          0.02

Model Class:                                        LP

Total variables:                   20
Nonlinear variables:                0
Integer variables:                  0

Total constraints:                 11
Nonlinear constraints:              0

Total nonzeros:                    37
Nonlinear nonzeros:                 0
```

Variable	Value	Reduced Cost
A10	42658.88	0.000000
BG5	0.000000	0.4334355
BM2	0.000000	0.8705834
A1	2000.000	0.000000
BG1	0.000000	0.6076592
BM1	0.000000	0.9125497
A2	4150.000	0.000000
BG2	0.000000	0.5652643
A3	6961.250	0.000000
BG3	0.000000	0.5258273
BM3	0.000000	1.819147
A4	9983.344	0.000000
BG4	0.000000	0.4891417
BM4	0.000000	1.692230
A5	13732.09	0.000000
BM5	0.000000	1.574168
A6	18262.00	0.000000
A7	23131.65	0.000000
A8	28866.53	0.000000
A9	35031.52	0.000000

Row	Slack or Surplus	Dual Price
1	45858.29	1.000000
2	0.000000	-2.061032
3	0.000000	-1.917239
4	0.000000	-1.783478
5	0.000000	-1.659049
6	0.000000	-1.543302
7	0.000000	-1.435629
8	0.000000	-1.335469
9	0.000000	-1.242297
10	0.000000	-1.155625
11	0.000000	-1.075000

Problem 10 : Final Solution

A1 $= 2000$
A2 $= 4150$
A3 $= 6961$
A4 $= 9983.34$
A5 $= 13732.09$
A6 $= 18262$
A7 $= 231313.65$
A8 $= 28866$
A9 $= 35031$
A10 $= 42658.88$

Problem 10 : Final Solution

cont

$BG1 = 0$
$BG2 = 0$
$BG3 = 0$
$BG4 = 0$
$BG5 = 0$
$BM1 = 0$
$BM2 = 0$
$BM3 = 0$
$BM4 = 0$
$Z = 45858.29$

References

Hamdy A. Taha. (2004). Introducción a la programación Lineal. En Investigación de operaciones(11-67). México : PEARSON Education.