SENSITIVITY ANALYSIS IN LINEAR PROGRAMMING

Part 2: Examples

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examples

- Nurse Staffing Problem
- A Gasoline Blending Problem
- Production Planning

SEQUOIA CLINIC NURSE STAFFING PROBLEM

Required # nurses on duty (minimum):

MON	TUES	WED	THUR	FRI	SAT	SUN
17	14	12	15	22	10	15

- Need work schedule for full-time nurses with two consecutive days off per week. Pay is $120/day, except for Saturdays ($150) and Sundays ($180)
- May also hire part-time nurses who will work Fri-Sun-Mon schedules, for $240/weekend.

Decision Variables

MON = # full-time nurses who start 5-day shift on Mondays,

TU = # full-time nurses who start 5-day shift on Tuesdays

WED = etc.

P = # part-time nurses


```
:LOOK ALL

MIN    600 MON + 630 TU + 690 WED + 690 TH + 690 FR + 690 SA
     + 660 SU + 240 P
SUBJECT TO
     2)  MON + TH + FR + SA + SU + P      >=  17  <-- Monday
     3)  MON + TU + FR + SA + SU          >=  14  <-- Tuesday
     4)  MON + TU + WED + SA + SU         >=  12  <-- Wednesday
     5)  MON + TU + WED + TH + SU         >=  15  <-- Thursday
     6)  MON + TU + WED + TH + FR + P     >=  22  <-- Friday
     7)  TU + WED + TH + FR + SA          >=  10  <-- Saturday
     8)  WED + TH + FR + SA + SU + P      >=  15  <-- Sunday
END
```

RQMTS for

: PICTURE

	MON	TU	WED	TH	FR	SA	SU	P		
1:	C	C	C	C	C	C	C	C		MIN
2:	1			1	1	1	1	1	>	B
3:	1	1			1	1	1		>	B
4:	1	1	1			1	1		>	B
5:	1	1	1	1			1		>	B
6:	1	1	1	1	1			1	>	B
7:		1	1	1	1	1			>	A
8:			1	1	1	1	1	1	>	B

: GO

OBJECTIVE FUNCTION VALUE

1) 12180.0000

VARIABLE	VALUE	REDUCED COST
MON	2.000000	0.000000
TU	9.000000	0.000000
WED	0.000000	180.000000
TH	1.000000	0.000000
FR	0.000000	60.000000
SA	0.000000	60.000000
SU	3.000000	0.000000
P	11.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	-180.000000
3)	0.000000	-180.000000
4)	2.000000	0.000000
5)	0.000000	-240.000000
6)	1.000000	0.000000
7)	0.000000	-210.000000
8)	0.000000	-60.000000

RANGES IN WHICH THE BASIS IS UNCHANGED

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
MON	600.000000	60.000000	180.000000
TU	630.000000	30.000000	180.000000
WED	690.000000	INFINITY	180.000000
TH	690.000000	180.000000	60.000000
FR	690.000000	INFINITY	60.000000
SA	690.000000	INFINITY	60.000000
SU	660.000000	180.000000	60.000000
P	240.000000	20.000000	180.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	17.000000	3.000000	0.500000
3	14.000000	1.000000	1.000000
4	12.000000	2.000000	INFINITY
5	15.000000	0.500000	1.000000
6	22.000000	1.000000	INFINITY
7	10.000000	3.000000	0.500000
8	15.000000	1.000000	3.000000

: TABLEAU

THE TABLEAU

ROW	(BASIS)	MON	TU	WED	TH
1	ART	0.000	0.000	180.000	0.000
2	P	0.000	0.000	-1.000	0.000
3	MON	1.000	0.000	-1.000	0.000
4	SLK 4	0.000	0.000	-1.000	0.000
5	TH	0.000	0.000	1.000	1.000
6	SLK 6	0.000	0.000	-2.000	0.000
7	TU	0.000	1.000	0.000	0.000
8	SU	0.000	0.000	1.000	0.000

ROW	FR	SA	SU	P	SLK 2
1	60.000	60.000	0.000	0.000	180.000
2	3.000	3.000	0.000	1.000	-1.000
3	0.000	0.000	0.000	0.000	-1.000
4	1.000	0.000	0.000	0.000	0.000
5	-1.000	-1.000	0.000	0.000	0.000
6	3.000	4.000	0.000	0.000	-2.000
7	2.000	2.000	0.000	0.000	0.000
8	-1.000	-1.000	1.000	0.000	1.000

ROW	SLK 3	SLK 4	SLK 5	SLK 6	SLK 7
1	180.000	0.000	240.000	0.000	210.000
2	-1.000	0.000	2.000	0.000	-1.000
3	0.000	0.000	0.000	0.000	0.000
4	-1.000	1.000	0.000	0.000	0.000
5	1.000	0.000	-1.000	0.000	0.000
6	-1.000	0.000	2.000	1.000	-2.000
7	-1.000	0.000	1.000	0.000	-1.000
8	0.000	0.000	-1.000	0.000	1.000

ROW	SLK 8	
1	60.	-0.12E 05
2	0.000	11.000
3	1.000	2.000
4	0.000	2.000
5	0.000	1.000
6	1.000	1.000
7	0.000	9.000
8	-1.000	3.000

Parametric Programming on the Right-Hand-Side

PARARHS
ROW:**2**
NEW RHS VAL=**30**

VAR OUT	VAR IN	PIVOT ROW	RHS VAL	DUAL PRICE BEFORE PIVOT	OBJ VAL
			17.0000	-180.000	12180.0
SU	FR	5	20.0000	-180.000	12720.0
SLK 4	SA	4	22.0000	-240.000	13200.0
SLK 6	SLK 8	6	24.5000	-240.000	13800.0
TU	SLK 4	7	24.5000	-240.000	13800.0
FR	SLK 6	5	26.5000	-240.000	14280.0
			30.0000	-240.000	13440.0

Questions

- On which days is the minimum req'd # of nurses exceeded? ... by how much?
- If you could shift admissions from one day to another and thus reduce staffing reqmts for one day and increase them for another day, which days would you choose?
- How much can the wages of the part-time nurses increase without affecting the optimal solution?

Questions

- Suppose that one of the doctors has requested that his daughter (a nurse) be scheduled to work the shift beginning Wednesday. How will this affect the cost and the schedule?
- Suppose that one more nurse is required on Monday, raising the required number to 18. How will this affect the cost and the schedule?

A Gasoline Blending Problem

A refinery takes four raw gasolines, blends them, and produces three types of fuel.

Raw Gas Type	Octane Rating	Available (Barrels/day)	Price ($/barrel)
1	68	4000	31.02
2	86	5050	33.15
3	91	7100	36.35
4	99	4300	38.75

Fuel blend Type	Minimum Octane rating	Selling price Price ($/barrel)	Demand Pattern (barrels/day)
1	95	45.15	≤ 10,000
2	90	42.95	any amt. can be sold
3	85	40.99	≥ 15,000

Raw gasolines not used in blending can be sold at
$38.95/barrel if octane rating ≥ 90
$36.85/barrel if octane rating < 90

Variables:

X_{ij} = barrels/day of raw gasoline of type i used in making fuel type j (i=1,2,3,4; j=1,2,3)

Y_i = barrels/day of raw gasoline type i sold "as is" on the market (i=1,2,3,4)

Questions:

1.) 5050 barrels/day of raw gas type #2 is now available for $33.15/barrel.

- If more would be available, would the refinery be able to increase their profit?
- What is the maximum price/barrel that the refinery should be willing to pay for the type #2 gasoline?
- What is the quantity of gasoline that they should be willing to buy at that price?
- If there were an additional 10 barrels/day available at the original price ($33.15/barrel), how would it be used, i.e., how would the optimal solution be changed?

Questions:

2.) In the optimal solution, raw gasoline type #3 is not sold on the market, even though it can be sold for more than the price paid by the refinery.

- What increase in the selling price of this gasoline would be required in order to make its sale optimal?
- If it could be sold at this price, how much would be sold? What would be the effect on the quantities of the blends produced?

Questions:

3.) The optimal solution indicates that no more than the minimum requirement for fuel blend type #3 is produced.

- If the requirement for fuel blend type #3 were decreased by 1 barrel/day, how much additional profit could be made by the refinery?

LINDO output

```
MAX   14.13 X11 + 12 X21 + 8.8 X31 + 6.4 X41 + 11.93 X12 + 9.8 X22
      + 6.6 X32 + 4.2 X42 + 9.97 X13 + 7.84 X23 + 4.64 X33 + 2.24 X43
      + 5.83 Y1 + 3.7 Y2 + 2.6 Y3 + 0.2 Y4
SUBJECT TO
        2)   - 27 X11 - 9 X21 - 4 X31 + 4 X41   >=  0
        3)   - 22 X12 - 4 X22 + X32 + 9 X42     >=  0
        4)   - 17 X13 + X23 + 6 X33 + 14 X43    >=  0
        5)        X11 + X12 + X13 + Y1           =  4000
        6)        X21 + X22 + X23 + Y2           =  5050
        7)        X31 + X32 + X33 + Y3           =  7100
        8)        X41 + X42 + X43 + Y4           =  4300
        9)        X11 + X21 + X31 + X41         <=  10000
       10)        X13 + X23 + X33 + X43         >=  15000
END

OBJECTIVE FUNCTION VALUE

 1)    140216.500
```

Gasoline Blending

A refinery takes four raw gasolines, blends them, and produces three types of fuel.

Data about raw gasolines

Raw gas	Octane rating	Available (barrels/day	Cost ($/barrel)	Selling price ($/b)
1	68	4000	31.02	36.85
2	86	5050	33.15	36.85
3	91	7100	36.35	38.95
4	99	4300	38.75	38.95

Data about blended fuels

Fuel type	Min octane rating	Selling price ($/barrel)	Demand pattern
1	95	45.15	≤ 10000 barrels/day
2	90	42.95	Any amt can be sold
3	85	40.99	≥ 15000 barrels/day

The LINGO model:

```
MODEL: ! GASOLINE BLENDING PROBLEM;

SETS:
    RAW/1..4/:OCTANE,AVAIL,COST,PRAW,Y;
    FUEL/1..3/:MINOCT,PRICE,DEMAND;
    BLEND(RAW,FUEL):X;
ENDSETS

DATA:
!   attributes of raw gasolines;
    OCTANE= 68 86 91 95;
    AVAIL= 4000 5050 7100 4300;
    COST= 31.02 33.15 36.35 38.75;
    PRAW= 36.35 36.35 38.95 38.95;  ! selling price of raw gas;
!   attributes of blended fuel types;
    MINOCT= 95 90 85;
    PRICE= 45.15 42.95 40.99;
    DEMAND= 10000 0 15000;
ENDDATA
```



```
MAX= @SUM(RAW(I): (PRAW(I)-COST(I))*Y(I)
    + @SUM(FUEL(J): (PRICE(J)-COST(I))*X(I,J)));

    ! minimum octane requirement for each fuel;
@FOR(FUEL(J):
    @SUM(RAW(I): OCTANE(I)*X(I,J)) >=
                MINOCT(J)*@SUM(RAW(I): X(I,J));
);
    !maximum production of fuel #1;
    @SUM(RAW(I): X(I,1)) <= DEMAND(1);
    !minimum production of fuel #3;
    @SUM(RAW(I): X(I,3)) >= DEMAND(3);

    ! availability of raw gasolines;
@FOR(RAW(I):
    @SUM(FUEL(J): X(I,J)) + Y(I) <= AVAIL(I);
);
END
```


The LINDO model generated by LINGO:

```
MAX     14.13 X( 1, 1) + 11.93 X( 1, 2) + 9.97 X( 1, 3) + 12 X( 2, 1)
     + 9.8 X( 2, 2) + 7.84 X( 2, 3) + 8.8 X( 3, 1) + 6.6 X( 3, 2)
     + 4.64 X( 3, 3) + 6.4 X( 4, 1) + 4.2 X( 4, 2) + 2.24 X( 4, 3)
     + 5.33 Y( 1) + 3.2 Y( 2) + 2.6 Y( 3) + .2 Y( 4)
SUBJECT TO
2]- 27 X( 1, 1) - 9 X( 2, 1) - 4 X( 3, 1) >=   0
3]- 22 X( 1, 2) - 4 X( 2, 2) + X( 3, 2) + 5 X( 4, 2) >=   0
4]- 17 X( 1, 3) + X( 2, 3) + 6 X( 3, 3) + 10 X( 4, 3) >=   0
5]  X( 1, 1) + X( 2, 1) + X( 3, 1) + X( 4, 1) <=   10000
6]  X( 1, 3) + X( 2, 3) + X( 3, 3) + X( 4, 3) >=   15000
7]  X( 1, 1) + X( 1, 2) + X( 1, 3) + Y( 1) <=   4000
8]  X( 2, 1) + X( 2, 2) + X( 2, 3) + Y( 2) <=   5050
9]  X( 3, 1) + X( 3, 2) + X( 3, 3) + Y( 3) <=   7100
10]  X( 4, 1) + X( 4, 2) + X( 4, 3) + Y( 4) <=   4300
END
```

The solution found by LINGO:

Primal solution

Variable	Value	Reduced Cost
X(1, 3)	2820.370	0.0000000
X(2, 3)	5050.000	0.0000000
X(3, 3)	7100.000	0.0000000
X(4, 1)	4270.370	0.0000000
X(4, 3)	29.62963	0.0000000
Y(1)	1179.630	0.0000000

Dual solution

Row	Slack or Surplus	Dual Price
2	0.0000000	-0.3259259
3	0.0000000	-0.3000000
4	0.0000000	-0.3259259
5	5729.630	0.0000000
6	0.0000000	-0.9007407
7	0.0000000	5.330000
8	0.0000000	9.066667
9	0.0000000	7.496296
10	0.0000000	6.400000

Range analysis

Ranges in which the basis is unchanged:

Objective Coefficient Ranges

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Y(1)	5.330000	6.600000	2.432000
Y(2)	3.200000	5.866667	INFINITY
Y(3)	2.600000	4.896296	INFINITY
Y(4)	0.2000000	6.200000	INFINITY
X(1, 1)	14.13000	INFINITY	0.0
X(1, 2)	11.93000	3.080000	2.566667
X(1, 3)	9.970000	0.0	8.800000
X(2, 1)	12.00000	0.0	INFINITY
X(2, 2)	9.800000	0.4666667	INFINITY
X(2, 3)	7.840000	INFINITY	0.0
X(3, 1)	8.800000	0.0	INFINITY
X(3, 2)	6.600000	0.5962963	INFINITY
X(3, 3)	4.640000	INFINITY	0.0
X(4, 1)	6.400000	INFINITY	0.0
X(4, 2)	4.200000	0.7000000	INFINITY
X(4, 3)	2.240000	0.0	INFINITY

Righthand Side Ranges

Row	Current RHS	Allowable Increase	Allowable Decrease
2	0.0	0.0	31850.00
3	0.0	0.0	25951.85
4	0.0	76150.00	800.0000
5	10000.00	INFINITY	5729.630
6	15000.00	3185.000	47.05882
7	4000.000	INFINITY	1179.630
8	5050.000	44.44444	3538.889
9	7100.000	34.78261	5013.043
10	4300.000	5729.630	4270.370

VARIABLE	VALUE	REDUCED COST
X11	633.213900	.000000
X21	.000000	.000000
X31	.000000	0.000000
X41	4274.193300	.000000
X12	.000000	.000000
X22	.000000	.542424
X32	.000000	.693098
X42	.000000	.934175
X13	2824.194000	.000000
X23	5050.000000	.000000
X33	7100.000000	.000000
X43	25.806451	.000000
Y1	542.592600	.000000
Y2	.000000	5.533334
Y3	.000000	4.970370
Y4	.000000	7.429629

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-.307407
3)	.000000	-.277273
4)	.000000	-.307407
5)	.000000	5.830000
6)	.000000	9.233334
7)	.000000	7.570370
8)	.000000	7.629630
9)	5092.593000	.000000
10)	.000000	-1.085926

NO. ITERATIONS= 7

OBJECTIVE COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X11	14.130000	INFINITY	-.000002
X21	12.000000	.000000	INFINITY
X31	8.800000	0.000000	INFINITY
X41	6.400000	INFINITY	-.000001
X12	11.930000	2.283539	2.983333
X22	9.800000	.542424	INFINITY
X32	6.600000	.693098	INFINITY
X42	4.200000	.934175	INFINITY
X13	9.970000	-.000002	9.529629
X23	7.840000	INFINITY	.000000
X33	4.640000	INFINITY	0.000000
X43	2.240000	-.000001	INFINITY

(OBJECTIVE COEFFICIENT RANGES, continued)

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
Y1	5.830000	6.100000	2.931999
Y2	3.700000	5.533334	INFINITY
Y3	2.600000	4.970370	INFINITY
Y4	.200000	7.429629	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	.000000	17096.773000	14650.000000
3	.000000	.000000	11937.040000
4	.000000	87550.000000	800.000000
5	4000.000000	INFINITY	542.592600
6	5050.000000	44.444450	1627.778000
7	7100.000000	34.782610	3662.500000
8	4300.000000	3662.500000	4274.193300
9	10000.000000	INFINITY	5092.593000
10	15000.000000	1465.000000	47.058822

THE TABLEAU

ROW	(BASIS)	X11	X21	X31	X41	X12	X22
1	ART	0.000	0.000	.000	0.000	0.000	.542
2	X31	3.875	1.625	1.000	.000	.000	.333
3	X12	.000	.000	.000	.000	1.000	.182
4	X13	1.000	0.000	.000	.000	.000	-.333
5	Y1	.000	0.000	.000	.000	0.000	.152
6	X23	.000	1.000	.000	.000	.000	1.000
7	X41	-2.875	-.625	.000	1.000	.000	.333
8	X33	-3.875	-1.625	.000	.000	.000	-.333
9	SLK 9	0.000	.000	.000	.000	.000	-.667
10	X43	2.875	.625	.000	.000	.000	-.333

THE TABLEAU

ROW	X32	X42	X13	X23	X33	X43	Y1
1	.693	.934	0.000	0.000	0.000	0.000	.000
2	.426	.574	0.000	.000	.000	0.000	.000
3	-.045	-.409	.000	.000	.000	.000	.000
4	-.148	.148	1.000	0.000	.000	0.000	.000
5	.194	.261	0.000	0.000	.000	0.000	1.000
6	.000	.000	.000	1.000	.000	.000	.000
7	.426	.574	0.000	.000	.000	0.000	.000
8	.574	-.574	0.000	.000	1.000	0.000	.000
9	-.852	-1.148	0.000	.000	.000	0.000	.000
10	-.426	.426	0.000	.000	.000	1.000	.000

THE TABLEAU

ROW	Y2	Y3	Y4	SLK 2	SLK 3	SLK 4	SLK 9
1	5.533	4.970	7.430	.307	.277	.307	.000
2	.333	.426	.574	.144	.000	.019	.000
3	.000	.000	.000	.000	.045	.000	.000
4	-.333	-.148	.148	.037	.000	.037	.000
5	.333	.148	-.148	-.037	-.045	-.037	.000
6	1.000	.000	.000	.000	.000	.000	.000
7	.333	.426	.574	-.106	.000	.019	.000
8	-.333	.574	-.574	-.144	.000	-.019	.000
9	-.667	-.852	-1.148	-.037	.000	-.037	1.000
10	-.333	-.426	.426	.106	.000	-.019	.000

THE TABLEAU

ROW	SLK 10	RHS
1	1.1	0.14E+06
2	.315	2453.704
3	.000	.000
4	-.370	3457.407
5	.370	542.593
6	.000	5050.000
7	.315	2453.704
8	-.315	4646.296
9	-.630	5092.593
10	-.315	1846.296

Re-Solving the LP with zero demand for Type-3 blend

```
: ALTER 10 RHS
NEW COEFFICIENT? 0

: GO
     LP OPTIMUM FOUND AT STEP     6

     OBJECTIVE FUNCTION VALUE

     1)    149183.340
```


Re-Solving the LP with zero demand for Type-3 blend

VARIABLE	VALUE	REDUCED COST
X11	.000000	3.653458
X21	.000000	.068015
X31	4300.000000	.000000
X41	4300.000000	.000000
X12	.000000	3.340589
X22	700.000000	.000000
X32	2800.000000	.000000
X42	.000000	.108824
X13	255.882400	.000000
X23	4350.000000	.000000
X33	.000000	.927941
X43	.000000	2.521471
Y1	3744.118000	.000000
Y2	.000000	4.383530
Y3	.000000	4.429118
Y4	.000000	7.970883

Re-Solving the LP with zero demand for Type-3 blend

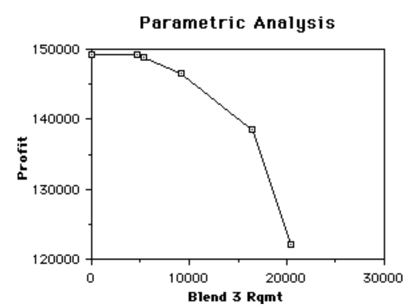
ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-.442721
3)	.000000	-.429118
4)	.000000	-.243529
5)	.000000	5.830000
6)	.000000	8.083529
7)	.000000	7.029118
8)	.000000	8.170883
9)	1400.000000	.000000
10)	4605.882300	.000000

Parametric Programming on Right-Hand-Side (demand for type-3 blend)

```
: PARA  10
NEW RHS?  25000

NO. ITERATIONS=     6
```

VAR OUT	VAR IN	PIVOT ROW	RHS VAL	DUAL PRICE BEFORE PIVOT	OBJ VAL
			.00	.000000	149183.
SLK 10	X12	10	4605.88	.000000	149183.
X22	X33	3	5347.06	-.573636	148758.
X32	X43	7	9135.29	-.573636	146585.
Y1	SLK 3	5	16465.0	-1.08593	138626.
X12	SLK 4	10	16465.0	-3.34518	138626.
X31	ART	2	20450.0	-4.16000	122048.
			25000.0	-INFINITY	INFEASIBLE



Production Planning for a Tire Manufacturer

An automobile tire company has the ability to produce both nylon and fiberglass tires.

During the next 3 months, they have agreed to deliver tires as follows:

Date	Nylon	Fiberglass
June 30	4000	1000
July 31	8000	5000
August 31	3000	5000
Total	15000	11000

The company has two presses:

- a Wheeling machine
- a Regal machine

and appropriate molds which can be used to produce these tires, with the following production hours available in the upcoming months:

Month	Wheeling machine	Regal machine
June	700	1500
July	300	400
August	1000	300

The production rates for each machine-and-tire combination, in terms of hours per tire, are as follows:

Tire	Wheeling machine	Regal machine
Nylon	0.15	0.16
Fiberglass	0.12	0.14

Economic Data

- The variable costs of producing tires are $5.00 per operating hour, regardless of which machine is being used or which tire is being produced.
- There is also an inventory-carrying charge of $0.10 per tire per month.
- Material costs for the nylon and fiberglass tires are $3.10 and $3.90 per tire, respectively.
- Finishing, packaging, and shipping costs are $0.23 per tire.
- Prices have been set at $7.00 per nylon tire and $9.00 per fiberglass tire.

Decision Variables:

WNt = Number of **n**ylon tires to be produced on the **W**heeling machine during month **t**

RNt = Number of **n**ylon tires to be produced on the **R**egal machine during month **t**

WGt = Number of fiber**g**lass tires to be produced on the **W**heeling machine in month **t**

RGt = Number of fiber**g**lass tires to be produced on the **R**egal machine during month **t**

In addition to the decision variables for production, we need to define variables for the inventory to be carried from one month to the next:

INt = Number of **n**ylon tires put into **i**nventory at the end of month **t**

IGt = Number of fiber**g**lass tires put into **i**nventory at the end of month **t**

Questions:

a) How should the production be scheduled in order to meet the delivery requirements at minimum cost?

b) What would be the total contribution to profit to be derived from this optimum schedule?

c) A new Wheeling machine is due to arrive at the beginning of September. For a $200 fee, it would be possible to expedite the arrival of the machine to August 2, making available 172 additional hours of Wheeling machine time in August. Should the machine delivery be expedited?

d) When would it be appropriate to allocate time for the yearly maintenance check-up on the two machines?


```
MIN   0.75 WN1 + 0.8 RN1 + 0.6 WG1 + 0.7 RG1 + 0.1 IN1 + 0.1 IG1
    + 0.75 WN2 + 0.8 RN2 + 0.6 WG2 + 0.7 RG2 + 0.1 IN2 + 0.1 IG2
    + 0.75 WN3 + 0.8 RN3 + 0.6 WG3 + 0.7 RG3
SUBJECT TO
     2)  0.15 WN1 + 0.12 WG1      <=  700    }
     3)  0.16 RN1 + 0.14 RG1      <=  1500   }
     4)  0.15 WN2 + 0.12 WG2      <=  300    }  machine time
     5)  0.16 RN2 + 0.14 RG2      <=  400    }  restrictions
     6)  0.15 WN3 + 0.12 WG3      <=  1000   }
     7)  0.16 RN3 + 0.14 RG3      <=  300    }
     8)  WN1 + RN1 - IN1           =  4000   }
     9)  WG1 + RG1 - IG1           =  1000   }
    10)  IN1 + WN2 + RN2 - IN2     =  8000   }  delivery
    11)  IG1 + WG2 + RG2 - IG2     =  5000   }  commitments
    12)  IN2 + WN3 + RN3           =  3000   }
    13)  IG2 + WG3 + RG3           =  5000   }
END
```

```
:PICTURE
    W R W R I I W R W R I I W R W R
    N N G G N G N N G G N G N N G G
    1 1 1 1 1 1 2 2 2 2 2 2 3 3 3 3

 1: T T T T U U T T T T U U T T T T MIN
 2: T   T '     '     '     '     ' < C
 3: ' T'  T  '  '  '  '  '  '  '  ' < D
 4:       '     T   T '     '     ' < C
 5:       '     ' T   T     '     ' < C
 6: '  '  '  '  '  '  '  '  T  'T ' < C
 7:       '     '     '     ' T   T < C
 8: 1 1   '-1   '     '     '     ' = D
 9: '  '1 1  -1 '  '  '  '  '  '  ' = C
10:       ' 1   1 1   '-1   '     ' = D
11:       '   1 '   1 1  -1 '     ' = D
12: '  '  '  '  '  '  ' 1'  1 1'  ' = D
13:       '     '     '   1 '   1 1 = D
```

```
:GO
LP OPTIMUM FOUND AT STEP    12

OBJECTIVE FUNCTION VALUE

1)    19173.3320
```

This is cost of machine time and inventory storage only

Profit is computed by calculating total revenues and subtracting this variable cost, together with cost of materials, finishing, packaging, etc.

VARIABLE	VALUE	REDUCED COST
WN1	1866.667000	.000000
RN1	7633.333000	.000000
WG1	3500.000000	.000000
RG1	.000000	.060000
IN1	5500.000000	.000000
IG1	2500.000000	.000000
WN2	.000000	.025000
RN2	2500.000000	.000000
WG2	2500.000000	.000000
RG2	.000000	.047500
IN2	.000000	.200000
IG2	.000000	.200000
WN3	2666.667000	.000000
RN3	333.333100	.000000
WG3	5000.000000	.000000
RG3	.000000	.060000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	.333333
3)	278.666740	.000000
4)	.000000	1.166667
5)	.000000	.625000
6)	.000000	.333333
7)	246.666700	.000000
8)	.000000	-.800000
9)	.000000	-.640000
10)	.000000	-.900000
11)	.000000	-.740000
12)	.000000	-.800000
13)	.000000	-.640000

OBJECTIVE COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
WN1	.750000	.025000	.059375
RN1	.800000	.075000	.050000
WG1	.600000	.047500	.020000
RG1	.700000	INFINITY	.060000
IN1	.100000	.025000	.054286
IG1	.100000	.047500	.020000
WN2	.750000	INFINITY	.025000
RN2	.800000	.054286	INFINITY
WG2	.600000	.020000	INFINITY
RG2	.700000	INFINITY	.047500
IN2	.100000	INFINITY	.200000
IG2	.100000	INFINITY	.200000
WN3	.750000	.050000	.075000
RN3	.800000	.075000	.050000
WG3	.600000	.060000	INFINITY
RG3	.700000	INFINITY	.060000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	700.000	1145.000000	261.250100
3	1500.000	INFINITY	278.666740
4	300.000	300.000000	261.250100
5	400.000	880.000000	278.666740
6	1000.000	49.999960	231.250010
7	300.000	INFINITY	246.666700
8	4000.000	1741.667200	7633.333000
9	1000.000	2177.084000	3500.000000
10	8000.000	1741.667200	5500.000000
11	5000.000	2177.084000	2500.000000
12	3000.000	1541.667000	333.333100
13	5000.000	1927.084000	416.666320

THE TABLEAU

ROW	(BASIS)	WN1	RN1	WG1	RG1	IN1	IG1
1	ART	.000	.000	.000	.060	.000	.000
2	WN1	1.000	.000	.000	-.800	.000	.000
3	SLK 3	.000	.000	.000	.012	.000	.000
4	WG2	.000	.000	.000	.000	.000	.000
5	RN2	.000	.000	.000	.000	.000	.000
6	WN3	.000	.000	.000	.000	.000	.000
7	SLK 7	.000	.000	.000	.000	.000	.000
8	RN1	.000	1.000	.000	.800	.000	.000
9	WG1	.000	.000	1.000	1.000	.000	.000
10	IN1	.000	.000	.000	.000	1.000	.000
11	IG1	.000	.000	.000	.000	.000	1.000
12	RN3	.000	.000	.000	.000	.000	.000
13	WG3	.000	.000	.000	.000	.000	.000

THE TABLEAU

ROW	(BASIS)	WN2	RN2	WG2	RG2	IN2	IG2	WN3
1	ART	.025	.000	.000	.047	.200	.200	.000
2	WN1	1.000	.000	.000	-.800	.000	.800	.000
3	SLK 3	.000	.000	.000	.012	.160	.128	.000
4	WG2	1.250	.000	1.000	.000	.000	.000	.000
5	RN2	.000	1.000	.000	.875	.000	.000	.000
6	WN3	.000	.000	.000	.000	.000	-.800	1.000
7	SLK 7	.000	.000	.000	.000	-.160	-.128	.000
8	RN1	.000	.000	.000	-.075	-1.000	-.800	.000
9	WG1	-1.250	.000	.000	1.000	.000	-1.000	.000
10	IN1	1.000	.000	.000	-.875	-1.000	.000	.000
11	IG1	-1.250	.000	.000	1.000	.000	-1.000	.000
12	RN3	.000	.000	.000	.000	1.000	.800	.000
13	WG3	.000	.000	.000	.000	.000	1.000	.000

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THE TABLEAU

ROW	(BASIS)	RN3	WG3	RG3	SLK 2	SLK 3	SLK 4	SLK 5
1	ART	.000	.000	.060	.333	.000	1.167	.625
2	WN1	.000	.000	.000	6.667	.000	6.667	.000
3	SLK 3	.000	.000	.000	1.067	1.000	1.067	1.000
4	WG2	.000	.000	.000	.000	.000	8.333	.000
5	RN2	.000	.000	.000	.000	.000	.000	6.250
6	WN3	.000	.000	-.800	.000	.000	.000	.000
7	SLK 7	.000	.000	.012	.000	.000	.000	.000
8	RN1	.000	.000	.000	-6.667	.000	-6.667	-6.250
9	WG1	.000	.000	.000	.000	.000	-8.333	.000
10	IN1	.000	.000	.000	.000	.000	.000	-6.250
11	IG1	.000	.000	.000	.000	.000	-8.333	.000
12	RN3	1.000	.000	.800	.000	.000	.000	.000
13	WG3	.000	1.000	1.000	.000	.000	.000	.000

THE TABLEAU

ROW	(BASIS)	SLK 6	SLK 7	
1	ART	.33	.000	-0.19E+05
2	WN1	.000	.000	1866.667
3	SLK 3	.000	.000	278.667
4	WG2	.000	.000	2500.000
5	RN2	.000	.000	2500.000
6	WN3	6.667	.000	2666.667
7	SLK 7	1.067	1.000	246.667
8	RN1	.000	.000	7633.333
9	WG1	.000	.000	3500.000
10	IN1	.000	.000	5500.000
11	IG1	.000	.000	2500.000
12	RN3	-6.667	.000	333.333
13	WG3	.000	.000	5000.000

PARAMETRIC PROGRAMMING

```
:ALTER 13 RHS
NEW COEFFICIENT?  0
:GO
 LP OPTIMUM FOUND AT STEP     1

      OBJECTIVE FUNCTION VALUE

      1)    16156.670
```

Re-Solving LP with zero RHS in Row 13

PARAMETRIC PROGRAMMING

```
:PARA 13
NEW RHS?  10000

 NO. ITERATIONS=     1
```

VAR OUT	VAR IN	PIVOT ROW	RHS VAL	DUAL PRICE BEFORE PIVOT	OBJ VAL
			.000000	-.600000	16156.7
SLK 6	RN3	6	4583.33	-.600000	18906.7
SLK 7	IN2	7	6927.08	-.640000	20406.7
WN3	IG2	12	8333.33	-.800000	21531.7
SLK 3	ART	3	9104.17	-.840000	22179.2
			10000.00	-INFINITY	INFEASIBLE