

## Review Solutions, Exam 2, Operations Research

1. Prove the weak duality theorem: For any  $\mathbf{x}$  feasible for the primal and  $\mathbf{y}$  feasible for the dual, then...

HINT: Put the primal so that  $A\mathbf{x} \leq \mathbf{b}$  and the dual so that  $A^T\mathbf{y} \geq \mathbf{c}$ .

SOLUTION: With the primal and dual in normal form, then

$$\mathbf{y}^T A\mathbf{x} \leq \mathbf{y}^T \mathbf{b} \quad \text{and} \quad \mathbf{x}^T A^T \mathbf{y} \geq \mathbf{x}^T \mathbf{c}$$

Noting that  $\mathbf{x}^T A^T \mathbf{y} = (A\mathbf{x})^T \mathbf{y} = \mathbf{y}^T (A\mathbf{x})$ , we get that:

$$\mathbf{c}^T \mathbf{x} \leq \mathbf{y}^T A\mathbf{x} \leq \mathbf{b}^T \mathbf{y}$$

2. Show that the solution to the dual is  $\mathbf{y} = (\mathbf{c}_B^T B^{-1})^T$  (if the primal and dual are both feasible).

HINT: Strong duality might be useful.

SOLUTION: Ignore the hint, which should have read: "Consider Row 0".

In the optimal tableau, the coefficients of Row 0 are all non-negative. Therefore,

$$\mathbf{c}_B^T B^{-1} A - \mathbf{c}^T \geq 0 \quad \Rightarrow \quad \mathbf{c}_B^T B^{-1} A \geq \mathbf{c}^T$$

The vectors on the right and left are in rows. Transpose them for columns:

$$A^T (\mathbf{c}_B^T B^{-1})^T \geq \mathbf{c}$$

Therefore, if we define  $\mathbf{y} = (\mathbf{c}_B^T B^{-1})^T$ , we know that  $\mathbf{y}$  is feasible for the dual.

Now, is  $\mathbf{y}$  optimal for the dual? Now we can use strong duality:

$$\mathbf{y}^T \mathbf{b} = \mathbf{c}_B^T B^{-1} \mathbf{b} = \mathbf{c}^T \mathbf{x}$$

so  $\mathbf{y}$  is optimal for the dual.

3. Solve using big-M:

$$\begin{aligned} \max \quad z = & 2x_1 + 3x_2 \\ \text{st} \quad & 2x_1 + x_2 \geq 4 \\ & x_1 - x_2 \geq -1 \\ & x_2 \leq 3 \\ & x_1, x_2 \geq 0 \end{aligned}$$

*Side remark: In the third constraint, I meant to make the first variable less than 3, but we'll go ahead and solve the one that is written.*

SOLUTION: Notice that we do not want the negative  $b_2$ , so multiply that constraint by  $-1$ . This makes constraints 2 and 3 "normal" (with slack variables), so we only need one excess variable for the first constraint. This means we have only one artificial variable, and the tableau is:

$x_1$	$x_2$	$e_1$	$s_2$	$s_3$	$a_1$	rhs		$x_1$	$x_2$	$e_1$	$s_2$	$s_3$	$a_1$	rhs		
-2	-3	0	0	0	M	0	→	-2	-2M	-3	-M	M	0	0	0	-4M
2	1	-1	0	0	1	4		2	1	-1	0	0	1	4		
-1	1	0	1	0	0	1		-1	1	0	1	0	0	1		
0	1	0	0	1	0	3		0	1	0	0	1	0	3		

# Operations Research Exam Questions And Its Solutions

**Michal Rosen-Zvi**



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