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Prioritizing and Scheduling Portsmouth Gaseous Diffusion Plant Safeguards Upgrades

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Final Report

Prioritizing and Scheduling Portsmouth Gaseous Diffusion Plant Safeguards Upgrades

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MASTER

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Table of Contents

1.0	Background and Problem statement
2.0	Overview of the Methodology
3.0	Objective Classification with the Preference Model
3.1	Trade-offs between levels in each measure
3.2	Trade-offs between safeguards objective categories
4.0	Safeguards Objectives and Upgrade Projects
4.1	Safeguards objective attributes
4.2	Upgrade project attributes
5.0	Scheduling Optimization Assumptions
6.0	Optimization Results
7.0	Sensitivity Analysis and Application to Other Problems
7.1	Sensitivity to Perturbations in the Trade-Off Ratios
7.2	Equally-Weighted Objectives
7.3	Alternate Operating Scenarios for PORTS
7.4	Budget Modifications
Appendix A: Mathematical Description of Preference Model	
Appendix B: Technical Description of Scheduling Optimization	

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1.0 Background and Problem Statement

As part of the Site Safeguards and Security Plan (SSSP), facilities are required to develop a Resource Plan (RP). The Resource Plan provides documentation and justification for the facility's planned upgrades, including the schedule, priority, and cost estimates for the safeguards and security upgrades.

Portsmouth Gaseous Diffusion Plant (PORTS) management has identified and obtained funding approval for a number of safeguards and security upgrades, including line-item construction projects. These upgrade projects were selected to address a variety of concerns identified in the PORTS vulnerability assessments and other reviews performed in support of the SSSP process. However, budgeting and scheduling constraints do not make it possible to simultaneously begin implementation of all of the upgrade projects. A formal methodology and analysis are needed to explicitly address the trade-offs between competing safeguards objectives, and to prioritize and schedule the upgrade projects to ensure that the maximum benefit can be realized in the shortest possible time frame.

The purpose of this report is to describe the methodology we developed to support these upgrade project scheduling decisions. The report also presents the results obtained from applying the methodology to a set of the upgrade projects selected by PORTS S&S management. Data for the analysis are based on discussions with personnel familiar with the PORTS safeguards and security needs, the requirements for implementing these upgrades, and upgrade funding limitations. The analysis results presented here assume continued highly enriched uranium (HEU) operations at PORTS. However, the methodology developed is readily adaptable for the evaluation of other operational scenarios and other resource allocation issues relevant to PORTS.

2.0 Overview of the Methodology

Below we describe the methodology developed to analyze project scheduling decisions for PORTS. The methodology uses a preference model to quantify the relative importance of safeguards objectives, and an optimization model to select a schedule for upgrade projects implementation that maximizes the benefit of the projects over time.

Our approach follows these nine steps. Figure 2.1 shows these steps and highlights the information flow between the various models.

1. Elicit preference data from PORTS S&S management - The first step in the methodology was to interview PORTS S&S management to determine an appropriate classification structure for safeguards objectives. Safeguards objectives include meeting DOE order compliance requirements, ensuring adequate protection against theft or sabotage of special nuclear material (SNM), and maintaining effective operations. As indicated in the figure, our safeguards objective classification structure includes objective categories, measures associated with each category, and levels within each measure.

For example, through extensive interviews, we identified the objective category "Compliance with DOE Orders." We also determined that "Severity of Noncompliance" and "Previously Identified" are two important measures associated with this objective category. The two levels associated with the "Previously Identified" measure correspond to whether or not the noncompliance has been previously identified through DOE oversight, inspections, or self-assessments.

After the objective classification structure was completely determined, trade-off ratios that express the relative importance between pairs of objective categories, measures, and levels were assessed. Section 3 describes this objective classification structure and data gathering process in more detail.

2. Preference model - The data collected in step 1 was used to develop a preference model that measures the relative importance of competing objectives. This model produces coefficients for a multiattribute utility function that reflects the overall protection philosophy of PORTS S&S management. Appendix A provides a brief description of the mathematical basis for the preference model used.
3. Multiattribute utility function - The preference model generates a set of coefficients associated with the safeguards objective classification structure. A safeguards objective is classified using this structure and a numerical value is generated. Thus, the classification structure acts as a function, which generates a relative importance value for a given safeguards objective.
4. Safeguards objectives - PORTS S&S management has a variety of safeguards objectives that require upgrade projects. The multiattribute utility function can be used to generate a numerical value for each of

these objectives. The safeguards objectives are listed in Table 4.1 (classified).

5. Value of meeting objective - The numerical value generated by the multiattribute utility function for a particular safeguards objective is a measure of the relative importance of not meeting that objective for a one-year period. The multiattribute utility function is used to generate a value for each safeguards objective of concern. These values are used as input to the optimization model, and may be viewed as penalty terms.
6. Objective/project relationships, Upgrade project costs, and Budget - The set of upgrade projects required to satisfy each safeguard objective are used as input to the optimization model. The objective is considered met when all of these projects are 100% complete; credit is not given for partial completion of a project. It is important to note that a single project might address more than one objective, and that more than one project might be required to completely address a particular objective. These relationships are shown in Table 4.1 (classified). Individual project costs, and the annual safeguards and security upgrades budget are also used. These data are included in Section 4.
7. Optimization model - The optimization algorithm seeks to minimize the penalty associated with all unmet safeguards objectives by scheduling safeguards upgrade projects. All constraints identified in Step 6 are met during this process. The optimization model is discussed in Section 5 and in Appendix B.
8. Optimized schedule - The optimal upgrade project implementation schedule minimizes exposure to unmet safeguards objectives within the facility's operational and safeguards budget constraints. The results of the optimization process are shown in Section 6.
9. Sensitivity analysis - It is important to review the optimal schedule generated by the optimization algorithm for consistency with PORTS S&S management's goals. In addition, subjective judgements and modeling assumptions of the preference model that have large effects on the solution should be identified and reviewed. Sensitivity analysis is discussed in more detail in Section 7.

Figure 2.1 Upgrade Project Scheduling Methodology

The next section describes the assumptions and data used to develop the preference model. Section 4 describes the objectives, their relationship to the projects, and cost and schedule data pertaining to the projects. Section 5 provides a description of the assumptions used to develop the schedule optimization model, and Section 6 presents the results. In Section 7, we determine the sensitivity of the solution to various assumptions and inputs. The report also contains two appendices outlining the technical foundation of the preference model and the optimization approach used.

3.0 Objective Classification with the Preference Model

A preference model was developed to determine the relative importance of various safeguards system objectives. At the heart of the model is an objective classification structure into which individual objectives are mapped. Relative preferences for safeguards objectives are generated simply by mapping them into the objective classification structure. This classification structure is discussed below, and is shown in Figure 3.1.

Safeguards objective categories are at the highest level of this objective classification structure, as shown in Figure 3.1. The following five safeguards objective categories were identified by PORTS S&S management:

- A. Compliance with DOE orders
- B. Protection against SNM Theft
- C. Protection against Radiological Sabotage
- D. Protection against Industrial Sabotage
- E. Operational Effectiveness

Each safeguards objective is associated with one of these five categories. A second tier of safeguards objective classification is accomplished by including one or more measures within each category, as illustrated in Figure 3.1. For example, two measures associated with the category "Compliance" were included in the model; one measure, "Severity," reflects the severity of a DOE order violation. The other measure, "Previous Identification," refers to whether or not the violation has been identified in a previous inspection or audit by DOE Headquarters.

Each measure contains two or more levels for further classification of safeguards objectives. For example, the "Severity" measure contains one level associated with violating an order pertaining to the control of CAT I SNM, a second level associated with violating an order for control of CAT II SNM, and a third level associated with violating an order for control of classified information. As one might expect, the "Previous Identification" measure contains two levels corresponding to whether or not the violation had been previously identified by DOE. Thus, the relative importance of a particular safeguards objective is evaluated by determining which specific category, measures, and levels are associated with that objective. It is important to note that a safeguards objective will map into only one category, and into one level within each measure associated with that category.

Figure 3.1 Safeguards Objective Classification

After this safeguards objective classification structure was developed, PORTS S&S management's preferences among categories, levels, and measures were quantified by a series of trade-off questions. PORTS S&S management's preferences among levels within each measure were determined by asking trade-off question regarding the relative desirability of time delays in addressing concerns with different levels. For example a typical trade-off question would be posed as follows:

"How long would you delay correcting an order violation for the control of classified information in exchange for correcting a violation of an order relating to the control of CAT II SNM 1 year sooner ?"

Note that the answer to this question implies a relative importance between two levels within the "Severity" measure: (1) violating classified information-related

DOE orders and (2) violating CAT II SNM-related DOE orders. The relative importance of each level within a measure was established using these trade-off data. Relative preferences were assessed between measures and between objective categories using a similar technique.

Equivalent time delay was chosen as an appropriate common metric for the trade-offs because the ultimate scheduling decision would directly affect the time required to satisfy the various objectives.

Using the relative preference data, a utility function was developed that can be used to generate the relative importance of each safeguards objective. The function explicitly represents the subjective trade-offs determined for each category, measure, and level. For convenience, the function is scaled to produce values between 0 and 100 with 0 being the least important objective and 100 being the most important. The relative ranking of two objectives determines their relative priority over time (e.g if the utility of objective A is equal to 50 and B is 25, the decision maker would be indifferent between delaying A for 1 year and delaying B for 2 years).

Below we enumerate the measures and levels identified for each category, and the preference data and assumptions that were used in the preference model.

3.1 Trade-offs between levels within each measure

Objective Category A - Compliance with DOE orders

As indicated previously, the objective category "Compliance with DOE orders" contains a measure that reflects the severity of an order violation. PORTS S&S management identified possible 7 levels within this measure:

- A.1: Violation of DOE order for control of CAT I SNM
- A.2: Violation of DOE order for control of CAT II SNM
- A.3: Violation of DOE order for control of CAT III SNM
- A.4: Violation of DOE order for control of classified matter
- A.5: Violation of DOE order for control of CAT IV SNM
- A.6: Violation of DOE order for government property protection
- A.7: Violation of other DOE order requirement

We asked a series of trade-off questions to establish relative importances of levels within this measure. PORTS S&S management responded with the following statements:

*2 years delay correcting an A.1 violation is comparable to
4 years delay for an A.2 violation*

*1/2 year delay correcting an A.2 violation is comparable
to 4 years for an A.3 violation*

1 year delay correcting an A.3 violation is comparable to 4 years for an A.4 violation

1 year delay correcting an A.3 violation is comparable to 5 years for an A.5 violation

1 month delay correcting an A.3 violation is comparable to 4 years for an A.6 violation

1 year delay correcting an A.6 violation is comparable to 1 year for an A.7 violation

These responses to trade-off questions quantify the relative importance between levels in the "Severity" measure.

The second measure within the compliance category reflects whether or not the violation had been previously identified by an Inspection and Evaluation (I&E) or other audit. PORTS S&S management provided the following response to our trade-off question:

3 years delay in correcting a previously identified violation is comparable to 4 years of delay for a violation that has not been identified, independent of the severity of the violation.

This response is sufficient to establish the relative importance between the two levels in the "Previous Identification" measure. In addition, it indicates that this relative importance applies regardless of the level established for the "Severity" measure.

Objective Category B -Protection against SNM theft

"Severity" is the first measure associated with the "SNM Theft" objective category. Two considerations governing the definition of levels for this measure are whether or not the protection system meets the Master Safeguards and Security (MSSA) defined risk criteria, and whether or not the performance effectiveness is deemed satisfactory by PORTS S&S management. The following possible levels were defined in order of priority.

- B. 1: MSSA-defined High Risk
- B. 2: MSSA-defined Moderate Risk
- B. 3: Moderate effectiveness protecting CAT I
- B. 4: Low effectiveness protecting CAT II
- B. 5: Moderate effectiveness protecting CAT II
- B. 6: Low effectiveness protecting CAT III
- B. 7: Moderate effectiveness protecting CAT III

The following trade-offs were identified by PORTS S&S management to establish the quantitative preference relationship for levels within this measure:

1 year of delay correcting a B.1 theft severity concern is comparable to 2 years of delay for a B.2 concern

1 year of delay correcting a B.2 theft severity concern is comparable to 4 years of delay for a B.3 concern

1 year of delay correcting a B.3 theft severity concern is comparable to 1 year of delay for a B.4 concern

1 year of delay correcting a B.4 theft severity concern is comparable to 2 years of delay for a B.5 concern

1 year of delay correcting a B.5 theft severity concern is comparable to 4 years of delay for a B.6 concern

1 year of delay correcting a B.6 theft severity concern is comparable to 4 years of delay for a B.7 concern

"Threat" was the second measure established for the "SNM Theft" safeguards objective category. The possible levels were ranked in order of protection priority based on the subjective judgement of PORTS S&S management.

Type 1: Insider type A

Type 2: Insider type B

Type 3: Outsiders

Type 4: Mixture of outsiders and insiders

Type 5: Insider type C

The following trade-off statements were used to quantify the relative importance of levels within this measure.

3 years of delay correcting a type 1 theft threat concern is comparable to 4 years of delay for a type 2 concern

1 year of delay correcting a type 1 theft threat concern is comparable to 2 years of delay for a type 3 concern

1 year of delay correcting a type 3 theft threat concern is comparable to 1.5 years of delay for a type 4 concern

1 year of delay correcting a type 1 theft threat concern is comparable to 3 years of delay for a type 5 concern

Objective Category C -Protection against radiological sabotage

As indicated in Figure 3.1, the "Severity" and "Threat Type" measures were also identified for the radiological sabotage objective category. The severity measure contained two possible levels:

- C. 1: MSSA defined High Risk
- C. 2: MSSA defined Moderate Risk

We used the same relative importance ratio that was determined for the theft objective (i.e. a 2-to-1 ratio). For the threat type measure, we used the same ratios as those determined for the theft threat.

Objective Category D -Protection against industrial sabotage

The industrial sabotage objective category included measures, levels, and trade-off ratios identical to those used for the radiological sabotage category.

Objective Category E -Operational effectiveness

The operational effectiveness category is expressed in terms of the relative impact on the utilization of manpower and/or reduction in the number of required on-site SNM movements. Three possible levels are associated directly with this objective.

- E. 1: Significant impact
- E. 2: Moderate impact
- E. 3: Minimal impact

As used here, a "significant impact" implies that clearly identifiable improvements in manpower or facility utilization will be realized. A "moderate impact" implies that some improvements in manpower or facility utilization are likely. A "minimal impact" implies that the potential for improvements in manpower or facility utilization exists. The following trade-off statements were used to quantify the relative importance of these three levels.

1 year of delay in implementing an upgrade that provides a significant impact on operational effectiveness is comparable to 2 years of delay in implementing an upgrade that provides a moderate impact on operational effectiveness

1 year of delay in implementing an upgrade that provides a moderate impact on operational effectiveness is comparable to 2 years of delay in implementing an upgrade that provides a minimal impact on operational effectiveness

3.2 Trade-offs Between Objective Categories

The preference model also quantifies the relative importance among objective categories so that upgrades that address different objective categories can be compared. The following preference assessments were used to quantify this relationship:

4 years delay in correcting an A.1 compliance level is comparable to 1.5 years delay for a B. 2 severity SNM theft level

1 year of delay in correcting an A.2 compliance level is comparable to 8 years of delay for an E.1 operational effectiveness concern

1 year of delay in correcting a B.1 theft level is comparable to 3 years of delay for a C.1 radiological sabotage level

1 year of delay in correcting a B. 1 theft level is comparable to 7 years of delay for a D.1 industrial sabotage level

4.0 Protection Objectives and Upgrade Projects

In this section, we discuss how individual protection objectives selected by PORTS S&S management map into the objective classification scheme described in the previous section. Each protection objective addresses a unique weakness or vulnerability that applies to a specific act, threat, and facility location. We also describe the safeguards upgrade projects and how they relate to individual protection objectives.

4.1 Protection objective attributes

Table 4.1 (classified) summarizes the protection objectives that were identified to correct deficiencies existing within the safeguards and security system at PORTS. As indicated in the table, each protection objective has set of attributes

that can be used to map it into a unique location in the objective classification scheme described previously. The data in each column of this table are described below:

1. **Objective number:** A unique alpha-numeric identifier assigned to the protection objective (Y1,Y2,...,Y17). There is no implied priority related to this identifier.
2. **Location:** The location of the deficiency to be eliminated by the protection objective. This location is either a building number or is designated as "site-wide."
3. **Description of the Protection Objective:** A detailed description of the deficiency, threat, and act addressed by protection objective.
4. **Preference Model Classification:** The specific objective category, measures, and levels within the preference model that best classifies the objective.
5. **Computed Utility Value per Year:** The relative value of the objective based upon its classification.
6. **Required Upgrades:** The safeguards upgrade project(s) that must be completed before the protection objective is satisfied. It should be noted that one objective may require multiple safeguards upgrade projects, and a single safeguards upgrade project may apply to multiple objectives.

4.2 Safeguards Upgrade Project Attributes

Table 4.2 lists both funded and proposed safeguards upgrade projects. We describe the data in each column of the table below:

1. **Upgrade Identifier:** A unique alpha-numeric identifier assigned to the upgrade project (X1,X2,...,X17). There is no implied priority related to this identifier.
2. **Upgrade Location:** The location of the upgrade project. This location is either a building number or is designated as "site-wide."
3. **Upgrade Description:** A brief description of the upgrade project.
4. **Upgrade Project Cost:** The cost of the safeguards upgrade project, including design, construction, project management, and inspection.

5. **Minimum Time to Complete the Project:** This is the minimum time to complete an upgrade project assuming that the availability of construction and engineering labor is not a limitation.

Table 4.2 Safeguards Upgrade Projects

Upgrade Identifier	Location	Description	Cost (\$million)	Minimum Completion Time (yrs)
X1	345	Supplemental Alarm System	0.60	1.00
X2	345	Emergency Exit CCTV	0.90	1.00
X3	326	Penthouse Door Alarms	0.65	1.00
X4	326	Tunnel Alarms	0.20	1.00
X5	Site-wide	Card Reader	4.80	3.75
X6	Site-wide	Satellite Facility System	3.00	2.50
X7	705	Accountability Mods II	4.30	3.25
X8	Site-wide	Drive Gate/Barrier	0.15	1.00
X9	Site-wide	Badge Office	0.35	1.00
X10	Site-wide	Perimeter Fence Replacement	1.20	2.00
X11	326	Perimeter Alarm Replacement	5.90	3.00
X12	326	X-326/X111A Connection	0.35	1.00
X13	326	Additional Roto-Gates	0.10	1.00
X14	326	Emergency Exit CCTV	1.40	2.50
X15	326	Interior Security System	1.30	2.00
X16	345	Sub-sampling	0.85	1.00
X17	705	Emergency Exit CCTV	0.95	1.00
Total			27.00	

5.0 Scheduling Optimization Assumptions

To determine an upgrades implementation schedule that maximizes the benefit of the upgrades resources over time, an integer programming optimization model was formulated. Each objective is assigned a value in accordance with the preference model described in the Section 3. Conceptually, this value can be considered a penalty factor for not satisfying that particular objective in a given year.

The penalty realized for a particular objective is the product of the number of years the objective is not satisfied (i.e. the necessary upgrades are not completed), and the penalty factor. The overall penalty realized by a particular schedule is the sum of the individual penalties realized by each objective. The goal of the optimization is to identify the upgrades implementation schedule that achieves the smallest possible value for this overall penalty and that satisfies budget and logistical constraints.

Three five year funding profiles were analyzed:

- (1) Full budget: all line-item projects requested by PORTS S&S management,
- (2) Approved budget: excludes projects placed on hold by DOE Headquarters, and
- (3) Current budget: reflects actual expenditures during FY 91 of \$0.05 million.

These budgets are shown below in Table 5.1.

Table 5.1 Upgrade Project Budgets

	Total(\$M)	Year 1	Year 2	Year 3	Year 4	Year 5
(1) Full	27	2.6	7.7	9.9	5.2	1.5
(2) Approved	16.15	1.0	4.7	5.0	4.8	1.6
(3) Current	16.15	0.05	2.5	5.45	5.5	2.65

In addition, the following assumptions were incorporated in the optimization model formulation:

1. Any project could be worked on in any year, but the total amount spent on all projects within a year must be less than or equal to the amount budgeted for that year.
2. An objective is satisfied the year after all of its required upgrades are completed.
3. An upgrade is considered complete in the year when the balance of the total cost has been allocated; credit is not given for partial completion.
4. All upgrades with costs less than \$1.0 M could be completed within a year, if desired.
5. Projects having multiple year requirement of N years can not allocate more than 150% of the average annual yearly cost in any given year (this restriction ensures that large multi-year projects are not completed in a single year).

6.0 Optimization Results

An optimization model, described in the previous section and in Appendix B, was solved to obtain the optimal upgrade project implementation schedule. The solution assuming the full budget (17 upgrade projects), is shown in Tables 6.1 and 6.2.

Table 5.1 Optimal Upgrade Implementation Schedule - Full Budget

		Annual expenditures (\$M)					
	Task	Cost(\$M)	Year 1	Year 2	Year 3	Year 4	Year 5
1	X-345 Supplemental Alarm System	0.60		0.6			
2	X-345 Emergency Exit CCTV	0.90	0.15	0.75			
3	X-326 Penthouse Door Alarms	0.65			0.65		
4	X-326 Tunnel Alarms	0.20			0.2		
5	Card Reader	4.80		1.2	1.8	1.8	
6	Satellite Facility System	3.00		1.5	1.5		
7	X-705 Accountability Mods II	4.30			2.15	2.15	
8	Drive Gate/Barrier	0.15			0.15		
9	Badge Office	0.35	0.35				
10	Perimeter Fence Replacement	1.20				0.55	0.65
11	X-326 Perimeter Alarm Replacement	5.90		2.95	2.95		
12	X-326/X111A Connection	0.35	0.35				
13	X-326 Additional Roto-Gates	0.10	0.1				
14	X-326 Emergency Exit CCTV	1.40	0.7	0.7			
15	X-326 Interior Security System	1.30			0.5	0.8	
16	X-345 Sub-sampling	0.85					0.85
17	X-705 Emergency Exit CCTV	0.95	0.95				
	Total:	27	2.6	7.7	9.9	5.3	1.5
	Budget Constraint:		2.6	7.7	9.9	5.3	1.5

Table 6.2 Chart of Upgrade Implementation Schedule - Full Budget

	Task	Cost(\$M)	Year 1	Year 2	Year 3	Year 4	Year 5
1	X-345 Supplemental Alarm System	0.60		*****			
2	X-345 Emergency Exit CCTV	0.90	*****	*****			
3	X-326 Penthouse Door Alarms	0.65			*****		
4	X-326 Tunnel Alarms	0.20			*****		
5	Card Reader	4.80		*****	*****	*****	
6	Satellite Facility System	3.00		*****	*****		
7	X-705 Accountability Mods II	4.30			*****	*****	
8	Drive Gate/Barrier	0.15			*****		
9	Badge Office	0.35	*****				
10	Perimeter Fence Replacement	1.20				*****	*****
11	X-326 Perimeter Alarm Replacement	5.90		*****	*****		
12	X-326/X111A Connection	0.35	*****				
13	X-326 Additional Roto-Gates	0.10	*****				
14	X-326 Emergency Exit CCTV	1.40	*****	*****			
15	X-326 Interior Security System	1.30			*****	*****	
16	X-345 Sub-sampling	0.85					*****
17	X-705 Emergency Exit CCTV	0.95	*****				

In this optimized schedule, projects 2, 9, 12, 13, 14, and 17 are given priority and completed early, while projects 10, 15, and 16 are deferred until later periods.

It is important to note that some of the cash flows in this schedule can be modified without affecting the overall objective. For example, \$0.15 M of expenditures for project 1 could be moved forward to year 1 in exchange for moving a like amount of expenditures for project 2 from year 1 to year 2. Because both projects 1 and 2 have the same completion time under this new expenditure pattern, the penalty term in the optimization model remains unchanged (it is only a function of the project completion times).

As a general rule, if expenditures can be modified without changing completion times or violating annual budget constraints, then there will be no change in the penalty term. Thus, the analyst is provided some degree of freedom in scheduling expenditures for projects.

We have also examined the approved-budget upgrade program in which only the first 10 upgrade projects are completed (the other 7 projects have been put on hold by DOE Headquarters). The results of the optimization analysis are shown below in Tables 6.3 and 6.4.

Table 6.3 Optimal Schedule for Upgrade Projects - Approved Budget

		Annual expenditures (\$M)					
	Task	Cost(\$M)	Year 1	Year 2	Year 3	Year 4	Year 5
1	X-345 Supplemental Alarm System	0.60		0.6			
2	X-345 Emergency Exit CCTV	0.90		0.9			
3	X-326 Penthouse Door Alarms	0.65	0.65				
4	X-326 Tunnel Alarms	0.20	0.2				
5	Card Reader	4.80		1.2	1.8	1.8	
6	Satellite Facility System	3.00		1.5	1.5		
7	X-705 Accountability Mods II	4.30		0.5	1.65	2.15	
8	Drive Gate/Barrier	0.15	0.15				
9	Badge Office	0.35				0.35	
10	Perimeter Fence Replacement	1.20				0.5	0.7
	Total:	16.15	1	4.7	4.95	4.8	0.7
	Budget Constraint:		1	4.7	5	4.8	1.6

Table 6.4 Chart of Optimal Schedule for Projects - Approved Budget

	Task	Cost(\$M)	Year 1	Year 2	Year 3	Year 4	Year 5
1	X-345 Supplemental Alarm System	0.60		*****			
2	X-345 Emergency Exit CCTV	0.90		*****			
3	X-326 Penthouse Door Alarms	0.65	*****				
4	X-326 Tunnel Alarms	0.20	*****				
5	Card Reader	4.80		*****	*****	*****	
6	Satellite Facility System	3.00		*****	*****		
7	X-705 Accountability Mods II	4.30		*****	*****	*****	
8	Drive Gate/Barrier	0.15	*****				
9	Badge Office	0.35				*****	
10	Perimeter Fence Replacement	1.20				*****	*****

Under this schedule, projects 3, 4 and 8 are given priority while projects 9 and 10 are deferred until later years. Note that the annual budget constraints for years 3 and 5 are not binding. As was the case for the full-budget model, some cash flows can be shifted from year to year without affecting the penalty assessed for the schedule.

Finally, the current PORTS upgrade budget, which reflects expenditures in fiscal year 1991 and budget modifications recently made by DOE Headquarters, has been analyzed. The optimal safeguards project implementation schedule corresponding to this new budget is shown below.

Table 6.5 Optimal Schedule for Upgrades Projects - Current Budget

		Annual expenditures (\$M)					
	Task	Cost(\$M)	FY 91	FY 92	FY 93	FY 94	FY 95
1	X-345 Supplemental Alarm System	0.60	0.005	0.595			
2	X-345 Emergency Exit CCTV	0.90	0.005	0.895			
3	X-326 Penthouse Door Alarms	0.65	0.005	0.645			
4	X-326 Tunnel Alarms	0.20	0.005	0.195			
5	Card Reader	4.80	0.005		1.245	1.8	1.75
6	Satellite Facility System	3.00	0.005		1.5	1.495	
7	X-705 Accountability Mods II	4.30	0.005		2.145	2.15	
8	Drive Gate/Barrier	0.15	0.005	0.145			
9	Badge Office	0.35	0.005		0.345		
10	Perimeter Fence Replacement	1.20	0.005	0.025	0.215	0.055	0.9
	Total:	16.15	0.05	2.5	5.45	5.5	2.65
	Budget Constraint:		0.05	2.5	5.45	5.5	2.65

Table 6.6 Chart of Optimal Schedule for Projects - Current Budget

	Task	Cost(\$M)	FY 91	FY 92	FY 93	FY 94	FY 95
1	X-345 Supplemental Alarm System	0.60	*****	*****			
2	X-345 Emergency Exit CCTV	0.90	*****	*****			
3	X-326 Penthouse Door Alarms	0.65	*****	*****			
4	X-326 Tunnel Alarms	0.20	*****	*****			
5	Card Reader	4.80	*****		*****	*****	*****
6	Satellite Facility System	3.00	*****		*****	*****	
7	X-705 Accountability Mods II	4.30	*****		*****	*****	
8	Drive Gate/Barrier	0.15	*****	*****			
9	Badge Office	0.35	*****		*****		
10	Perimeter Fence Replacement	1.20	*****	*****	*****	*****	*****

As shown in the table, the current budget includes \$0.005 million in expenditures for each project in fiscal year 1991 for engineering, and increased budgets for years 1992-1995.

7.0 Sensitivity Analysis and Application to Other Problems

Because the analysis involves some subjective judgements regarding relative importance of safeguards objectives, we have included sensitivity analysis studies to determine which of these subjective judgements significantly affect the results. We have determined the sensitivity of the solution to key trade-off ratios assessed, and have generated a solution based an assumption of equally-preferred safeguards objectives. This latter solution can be compared to the solution obtained using the actual preferences to determine the value-added that can be attributed to the preference model.

In addition, the methodology developed is readily adaptable for the evaluation of other operational scenarios and budget issues relevant for PORTS. To illustrate this point, we have included PORTS upgrade analyses for different operating scenarios, and for various assumptions regarding the total budget and budget distribution over time.

7.1 Sensitivity to Perturbations In the Trade-off Ratios

Several modified optimization models were solved to determine the sensitivity of the project schedule to the subjective trade-off ratios assessed for development of the preference model. The modifications that were made to the preference model are listed below in Table 7.1.

Table 7.1 Trade-off Ratio Perturbations

Case	Ratio Modified	Base Value	Amount Changed
1	Compliance/Theft	0.19	+/- 50%
2	Compliance/Operational Effectiveness	16	+/- 50%
3	Cat I compliance/Cat II compliance	2	+/- 50%
4	Cat II compliance/Cat III compliance	4	+/- 50%
5	MSSA mod. risk/Cat I mod. effectiveness	2	+/- 50%
6	Cat I mod. effec./Cat II low effec.	4	+/- 50%
7	Insider type A/Outsiders	2	+/- 50%

Each of the 14 modifications shown in the above table were included in the preference model, and new coefficients were generated for the optimization model. For example, under Case 2 the ratio 16:1 was first increased by 50% to 24:1, and new objective coefficients were generated for the optimization model. The optimization model then generated a new schedule based upon the new objective coefficients. Also, the ratio was decreased by 50% to 8:1 and a different optimization model was solved.

The optimal schedule shown in Tables 6.3 and 6.4 — the approved budget problem — did not change when any of the above modifications were implemented. This implies that errors in assessing trade-off ratios that are smaller than 50% do not affect the optimal schedule for the reduced budget problem involving the 10 safeguards upgrades projects. However, larger perturbation in the ratios assessed did result in schedule changes in predictable ways.

This low level of sensitivity can be attributed in part to the highly constrained character of the problem. Note that, as shown in Table 6.3, the annual budgets are large in years 2, 3, and 4. This bulge in the budget profile has a tendency to force the large multi-year projects — projects 5, 6, and 7— to be implemented in these years. Projects 1, 2, 3, and 4 are overwhelmingly preferred to projects 8, 9, and 10, and thus are completed in years one and two. The solution would be more sensitive to the assessed trade-off ratios if the budget were leveled, because the scheduling algorithm would be able to shift cash flows more easily without violating budget constraints. Moreover, the solution is more sensitive to the assessed ratios in the 17 upgrade projects problem because there are more opportunities for modifying project completion dates.

7.2 Equally-weighted objectives

Another sensitivity study was performed using equally-weighted objectives in the preference structure (i.e. all trade-off ratios were set to 1.0). Under this scenario, upgrades that satisfy more than one objective will tend to move to the front of the schedule. This is because only the number, rather than the identity,

of objectives that are satisfied is important. This optimization model produced the following schedule.

Table 7.2 Schedule for Equally-Weighted Objectives - Approved Budget

		Annual expenditures (\$M)					
	Task	Cost(\$M)	Year 1	Year 2	Year 3	Year 4	Year 5
1	X-345 Supplemental Alarm System	0.60		0.6			
2	X-345 Emergency Exit CCTV	0.90		0.9			
3	X-326 Penthouse Door Alarms	0.65	0.65				
4	X-326 Tunnel Alarms	0.20	0.2				
5	Card Reader	4.80			1.4	1.8	1.6
6	Satellite Facility System	3.00		1.5	1.5		
7	X-705 Accountability Mods II	4.30		0.35	1.8	2.15	
8	Drive Gate/Barrier	0.15	0.15				
9	Badge Office	0.35		0.35			
10	Perimeter Fence Replacement	1.20		0.9	0.3		
	Total:	16.15	1	4.6	5	3.95	1.6
	Budget Constraint:		1	4.7	5	4.8	1.6

Note that relative to the optimal schedule shown in Figure 6.3, project 5 is delayed one year, while projects 9 and 10 are completed one year earlier. This schedule change results in an increase in the penalty function value from 232 to 249, an increase of 17 units.

To put this change in penalty function in perspective, we note that the penalty function generated by the preference model is scaled such that a 50 unit increase in penalty value is equivalent to 1 additional year of exposure to an MSSA-defined moderate risk of SNM theft. Thus, the 17 unit increase referred to above is equivalent to approximately 4 months of additional exposure to a moderate risk of SNM theft.

We also examined the full budget model using equally-weighted objectives. The new schedule is shown below.

Table 7.3 Schedule for Equally-Weighted Objectives - Full Budget

		Annual expenditures (\$M)					
	Task	Cost(\$M)	Year 1	Year 2	Year 3	Year 4	Year 5
1	X-345 Supplemental Alarm System	0.60	0.6				
2	X-345 Emergency Exit CCTV	0.90	0.9				
3	X-326 Penthouse Door Alarms	0.65			0.65		
4	X-326 Tunnel Alarms	0.20			0.2		
5	Card Reader	4.80			1.5	1.8	1.5
6	Satellite Facility System	3.00		0.15	1.5	1.35	
7	X-705 Accountability Mods II	4.30		1.63	0.52	2.15	
8	Drive Gate/Barrier	0.15	0.15				
9	Badge Office	0.35	0.35				
10	Perimeter Fence Replacement	1.20		0.3	0.9		
11	X-326 Perimeter Alarm Replacement	5.90		2.95	2.95		
12	X-326/X111A Connection	0.35	0.35				
13	X-326 Additional Roto-Gates	0.10	0.1				
14	X-326 Emergency Exit CCTV	1.40		0.7	0.7		
15	X-326 Interior Security System	1.30	0.15	0.17	0.98		
16	X-345 Sub-sampling	0.85		0.85			
17	X-705 Emergency Exit CCTV	0.95		0.95			
	Total:	27	2.6	7.7	9.9	5.3	1.5
	Budget Constraint:		2.6	7.7	9.9	5.3	1.5

Note the following changes relative to the optimal schedule shown in Figure 6.1:

Upgrade Project	Delayed (years)	Completed Earlier (years)
1		1
2		1
5	1	
6	1	
8		2
10		2
14	1	
15		1
16		3
17	1	

This extensive schedule change results in an increase in the penalty function value from 433.95 to 493.75, an increase of 60 units. This penalty increase is equivalent to 1.2 additional years of exposure to a moderate risk of SNM theft.

Thus, the benefits derived from development of a preference model correspond to the equivalent of 4 months reduction in exposure to a moderate risk of SNM theft for the approved budget scenario, and over 1 year reduction in exposure to a moderate risk of SNM theft for the full budget scenario.

7.3 Alternate Operating Scenarios for PORTS

The methodology developed in this report can be applied to alternate operating scenarios for PORTS. Under other operating scenarios, some of the objectives included in this study may no longer be relevant, and other objectives may be added. Deleting and adding objectives is easily accomplished within the framework of the preference model developed here. The preference model has been implemented on an electronic spreadsheet to facilitate this process.

To illustrate this process, we assume a new operating scenario for PORTS in which the first three objectives have been deleted. We further assume that safeguards projects 12 and 14 do not address any of the remaining objectives. Under such circumstances, there would no longer be any incentive to complete these two upgrades projects. Accordingly, we assume that they are not implemented, and we subtract their levelized costs from the annual budgets. The results of the optimization run under these assumptions are shown below.

Table 7.4 Schedule for PORTS Alternate Operating Scenario

		Annual expenditures (\$M)					
	Task	Cost(\$M)	Year 1	Year 2	Year 3	Year 4	Year 5
1	X-345 Supplemental Alarm System	0.60	0.6				
2	X-345 Emergency Exit CCTV	0.90	0.9				
3	X-326 Penthouse Door Alarms	0.65				0.65	
4	X-326 Tunnel Alarms	0.20		0.03	0.17		
5	Card Reader	4.80	0.15	1.8	1.8	1.05	
6	Satellite Facility System	3.00		1.5	1.5		
7	X-705 Accountability Mods II	4.30		2.15	2.15		
8	Drive Gate/Barrier	0.15	0.15				
9	Badge Office	0.35	0.35				
10	Perimeter Fence Replacement	1.20				0.3	0.9
11	X-326 Perimeter Alarm Replacement	5.90			2.95	2.95	
12	X-326/X111A Connection	0.35					
13	X-326 Additional Roto-Gates	0.10	0.1				
14	X-326 Emergency Exit CCTV	1.40					
15	X-326 Interior Security System	1.30		0.07	0.98		0.25
16	X-345 Sub-sampling	0.85		0.85			
17	X-705 Emergency Exit CCTV	0.95		0.95			
	Total:	27	2.25	7.35	9.55	4.95	1.15
	Budget Constraint:		2.25	7.35	9.55	4.95	1.15

A new schedule corresponding to a different operating scenario and corresponding set of objectives can be easily generated in this manner.

7.4 Budget Modifications

The methodology can easily be adapted to address a wide range of budget issues. We noted earlier that the 5 year budget profile severely constrains the allowable scheduling choices. Front-loaded or levelized budget profiles may lead to substantial reductions in exposure to risk. Another alternative budget configuration is a single constraint on the total expenditures throughout the 5 year time horizon. Minor modifications of the optimization model could be implemented in order to determine the relative value of such alternative budget configurations.

Finally, the methodology can also be modified to address project selection problems — cases where the budget is not sufficient to implement all safeguards upgrade projects. The optimization model would select the subset of the available upgrades projects that minimizes the penalty associated with unmet objectives, given the available budget.

Appendix A

Mathematical Description of the Preference Model

A Multiattribute Utility Function (MUF) that reflects the trade-off data assessed from the panel was developed in order to help compute relative values for safeguards objectives. This appendix describes the mathematical formulations used.

Figure 3.1 shows the overall structure of the objective classification scheme employed by the model. The first set of branches in the diagram represent the major protection goals, and are referred to in the body of the report as objective categories. As indicated in the figure, one or more measures are associated with each objective category. For example, the measures "Severity" and "Threat Type" are associated with the objective category "Theft." Finally, each measure contains a number of different levels.

Single Attribute Utility Functions for Levels within Measures

For each measure, a Single Attribute Utility Function (SUF) has been developed that determines relative importance of the levels within the measure. These SUFs are generated using the trade-off data assessed. Each SUF is normalized to the interval [0,1], where 1 corresponds to the most important concern. Note that the level 0 means that the particular measure is not applicable for the given safeguards objective (e.g. a safeguards objective that addresses a compliance concern would have level 0 setting for the theft/severity measure). Below we list SUFs for each measure assessed.

Table A.1 Compliance/Severity Measure SUF			
Level	Description	Ratio	Utility
0	not applicable		0
1	Violation of DOE order for control of CAT I SNM		1
2	Violation of DOE order for control of CAT II SNM	2	0.5
3	Violation of DOE order for control of CAT III SNM	8	0.0625
4	Violation of DOE order for control of Classified matter	4	0.015625
5	Violation of DOE order for control of CAT IV SNM	1.25	0.0125
6	Violation of DOE order for government property protection	9.6	0.001302
7	Violation of other DOE order requirement	1	0.001302

Table A.2 Compliance/Prev. Identified Measure SUF			
Level		Ratio	Utility
0	not applicable		0
1	Previously Identified in I&E		1
2	Not previously identified	1.33	0.75
Table A.3 Theft/Severity Measure SUF			
Level		Ratio	Utility
0	not applicable		0
1	MSSA defined High Risk		1
2	MSSA defined Moderate Risk	2	0.5
3	Moderate effectiveness protecting CAT I	4	0.125
4	Low effectiveness protecting CAT II	1	0.125
5	Moderate effectiveness protecting CATII	2	0.0625
6	Low effectiveness protecting CAT III	4	0.015625
7	Moderate effectiveness protecting CAT III	4	0.003906
Table A.4 Theft/Threat Measure SUF			
Level		Ratio	Value
0			0
1	Insider type A		1
2	Insider type B	1.33	0.75
3	Outsiders	1.5	0.5
4	Mixture of outsiders and insiders	1.2	0.416667
5	Insider type C	1.25	0.333333
Table A.5 Operational Effectiveness Measure SUF			
Level		Ratio	Value
0	not applicable		0
1	significant impact on effective utilization of manpower and/or reduction in the number of required SNM movements		1
2	moderate impact	2	0.5
3	some impact	2	0.25

Multiattribute utility function

The SUFs enumerated in the above table were combined to form a multiattribute utility function. This procedure was accomplished in two phases. First, a utility model was developed to combine the two measure-SUFs associated with each objective category. Second, the utility functions developed for each objective category were combined to form a single multiattribute utility function for the entire preference structure. We describe each of these two steps below.

First, utility functions that combine measures within an objective category were developed. During the interview process it was determined that the utility assigned to a particular level in one measure did not affect the preferences among levels in another measure. For example, the relative preferences among levels in the theft/severity measure did not depend upon the type of threat. This property is referred to in the multiattribute utility theory literature as mutual utility independence¹, and was established by asking a lottery question designed to test this hypothesis².

Mutual utility independence implies that this two-attribute utility function is multilinear³. Further, this multilinear form has an equivalent multiplicative representation⁴. A utility function that combines the two SUFs for a particular objective category would take the following form:

$$U_c = U_{m1}U_{m2}$$

where U_c is the utility associated with the objective category, U_{m1} is the utility associated with the first measure in that objective category, and U_{m2} is the utility associated with the second measure in that objective category.

Second, a utility function that combines the utility functions of different objective categories was developed. The additive independence property for this utility function was established by asking an appropriate lottery question⁵. The additive independence property implies that a utility function of additive form is appropriate for combining the utility functions of different objective categories. The complete multiattribute utility function for the entire preference structure can be expressed as follows:

$$MUF = S [K_a U_{a1}U_{a2} + K_b U_{b1}U_{b2} + K_c U_{c1}U_{c2} + K_d U_{d1}U_{d2} + K_e U_e]$$

where:

¹ Keeney, Ralph L., and Howard Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, Wiley, New York (1976).

² *ibid.*, pg. 226.

³ *ibid.*, Theorem 5.2, pg. 234.

⁴ *ibid.*, pg. 238.

⁵ *ibid.*, pg. 230.

Variable	SUF
U_{a1}	Compliance/Severity
U_{a2}	Compliance/Previously Identified
U_{b1}	Theft/Severity
U_{b2}	Theft/Threat Type
U_{c1}	Radiological Sabotage/Severity
U_{c2}	Radiological Sabotage/Threat Type
U_{d1}	Industrial Sabotage/Severity
U_{d2}	Industrial Sabotage/Threat Type
U_e	Operational Effectiveness

and K_a , K_b , K_c , K_d , K_e and S are suitably-chosen scaling constants derived below.

Scaling constants for the five objective categories are derived using the four objective category trade-off values assessed, and a normalization condition. The trade-off ratios used for this calculation are shown below.

Ratio	Value
K_a / K_b	0.1875
K_c / K_b	0.3333
K_d / K_b	0.143
K_e / K_b	0.01172

The normalization condition is expressed as follows:

$$K_a + K_b + K_c + K_d + K_e = 1.0$$

The following expression for K_b holds:

$$K_b = 1 / (1 + K_a / K_b + K_c / K_b + K_d / K_b + K_e / K_b)$$

Evaluating this expression yields $K_b = 0.597$. The other scaling constants are computed using this value for K_b and the appropriate ratio of constants.

Another scaling constant is introduced so that the MUF value associated with theft of a Cat I quantity of SNM is given a value of 100. This scaling constant, denoted, S , is given as follows:

$$S = 100 / K_b = 167.5$$

This expression is used to generate MUF values for safeguards objectives. They have been incorporated in an electronic spreadsheet model to facilitate revision of the input data. An example of the format of this model appears below in Table A.6.

Table A.6 Preference Model Implementation

Objective	<u>Compliance Category</u>		<u>Theft Category</u>		Oper.	Utility
	Severity Level	Previous ID Level	Severity Level	Threat Level	Effec. Level	
Example 1	2	1	0	0	0	9.38
Example 2	0	0	3	4	0	5.21
Example 3	0	0	0	1	1	1.17

The first example represents a safeguards objective related to the violation of a previously identified DOE order for control of CATII SNM. The second example represents an objective related to a moderate effectiveness protecting CAT I SNM from theft by a mixture of outsiders and insiders. The third example represents an action that would have a significant positive impact on manpower or facility utilization.

MUF values generated in this manner would appear in the objective function of the optimization model described in Appendix B.

Appendix B - Technical Description of Scheduling Optimization

This appendix provides a technical description of the mathematical programming model used to optimize the upgrades construction schedule. The purpose of the model is to find the schedule of upgrades expenditures that minimizes the penalty function derived from the preference model discussed in Appendix A.

The schedule optimization problem was formulated as a mixed-integer programming problem and solved using an off-the-shelf optimization package. An example model formulation involving 3 objectives and 3 upgrade projects is shown in Table B.1 below, in the format required by the optimization code. The 17 and 10-upgrade project optimization models are similar in structure to this example. We proceed with a discussion of the functions and constraints incorporated in this model.

The function shown in the first line of this model is a penalty function derived from the results of the preference model. The function contains 3 terms corresponding to the 3 hypothetical objectives that appear in the preference model shown in Table A.6. The coefficients of each of the terms correspond to the utility function values generated by the preference model. The values assigned to the variables Z_1 , Z_2 , and Z_3 are the number of years each objective remains unsatisfied. Thus, the objective function is a measure of the time-integrated penalty associated with not satisfying the objectives.

Constraints 2, 3, and 4 define the counter variables Z_1 , Z_2 , and Z_3 , respectively. These counter variables are defined in terms of the indicator variables Y_{it} , where i indexes the objective and t indexes the year. Each variable Y_{it} takes on a value 0 if safeguards upgrades required to satisfy objective i have been completed by year t . If the required safeguards upgrades have not been completed, then $Y_{it}=1$. Because we take credit for completed upgrades at the end of a year, $Y_{i1}=1$ for each objective i . Hence, Z_i can assume a value of 1 through 5, and counts the number of years that an objective is unmet.

Constraints 5) through 16) define the logical relationships between completion of S&S upgrades and satisfying objectives. Each objective is represented by four of these constraints, corresponding to years two through five, respectively (recall that it is not possible to have an objective satisfied during year 1). The objective variables Y_{it} , are linked to the S&S upgrades expenditure variables X_{jt} by these equations.

For example, consider constraints 5) through 8) corresponding to objective 1, and assume that completion of S&S upgrades 1 and 2 is required to satisfy objective 1. Further assume that upgrade projects 1 and 2 cost \$2 million and \$3 million to complete, respectively. With these assumptions, constraint 5) implies the following logical conditions:

$$Y_{12} = 1 \quad \text{if } X_{11} + X_{11} < 5 \quad (B.1)$$

$$Y_{12} = 0 \quad \text{if } X_{11} + X_{21} \geq 5 \quad (B.2)$$

Condition (B.1) implies that objective 1 is not satisfied in year 2 because the sum of expenditures on S&S upgrades 1 and 2 in year 1 is less than \$5 million (the amount required to complete these two upgrades). Condition (B.2) implies that objective 1 is satisfied in year 2 because the sum of expenditures on S&S upgrades 1 and 2 in year 1 is greater than or equal to \$5 million. Note that one and only one of these two logical conditions can be satisfied by assigning values to the variables X_{11} and X_{21} . Similarly, constraint 6) sets $Y_{13}=0$ if enough has been expended in years 1 and 2 to complete S&S upgrades 1 and 2. Constraints 7) and 8) correspond to completion of S&S upgrades in years 3 and 4, respectively.

Constraints 17) through 19) correspond to total expenditures on upgrades 1 through 3, respectively. For each upgrade project, the sum of expenditures over the five year period is forced to equal the cost of the upgrade.

Constraints 20) through 24) enforce the total upgrade budget for years one through five, respectively. The remainder of Table B.1 describes conditions on variables in the model. The variables labeled "INTE" are defined as integer variables in the model (they can only assume values of 0 or 1). The variables labeled "SUB" have the upper bounds shown. These upper bounds are required for multi-year projects, as described in Section 5 of the report.

Table B.1 - Optimization model for upgrades scheduling

MIN $9.38 Z_1 + 5.21 Z_2 + 1.17 Z_3$

SUBJECT TO

2) $1 + Y_{12} + Y_{13} + Y_{14} + Y_{15} = Z_1$

3) $1 + Y_{22} + Y_{23} + Y_{24} + Y_{25} = Z_2$

4) $1 + Y_{32} + Y_{33} + Y_{34} + Y_{35} = Z_3$

5) $5 Y_{12} + X_{11} + X_{21} \geq 5$

6) $5 Y_{13} + X_{11} + X_{21} + X_{12} + X_{22} \geq 5$

7) $5 Y_{14} + X_{11} + X_{21} + X_{12} + X_{22} + X_{13} + X_{23} = 5$

8) $5 Y_{15} + X_{11} + X_{21} + X_{12} + X_{22} + X_{13} + X_{23} + X_{14} + X_{24} \geq 5$

9) $2 Y_{32} + X_{11} \geq 2$

10) $2 Y_{33} + X_{11} + X_{12} \geq 2$

11) $2 Y_{34} + X_{11} + X_{12} + X_{13} \geq 2$

12) $2 Y_{35} + X_{11} + X_{12} + X_{13} + X_{14} \geq 2$

13) $0.1 Y_{62} + X_{31} \geq 0.1$

14) $0.1 Y_{63} + X_{31} + X_{32} \geq 0.1$

15) $0.1 Y_{64} + X_{31} + X_{32} + X_{33} \geq 0.1$

```

16) 0.1 Y65 + X31 + X32 + X33 + X34 >= 0.1
17) X11 + X12 + X13 + X14 + X15 = 2
18) X21 + X22 + X23 + X24 + X25 = 3
19) X31 + X32 + X33 + X34 + X35 = 0.1
20) X11 + X21 + X31 <= 1.1
21) X12 + X22 + X32 <= 1.5
22) X13 + X23 + X33 <= 1.5
23) X14 + X24 + X34 <= 0.5
24) X15 + X25 + X35 <= 0.5

END
INTE Y12
INTE Y13
INTE Y14
INTE Y15
INTE Y22
INTE Y23
INTE Y24
INTE Y25
INTE Y32
INTE Y33
INTE Y34
INTE Y35
SUB X11 1.0000
SUB X11 1.0000
SUB X11 1.0000
SUB X11 1.0000

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END

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