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Project Scheduling Tool for Maintaining Capability Interdependencies and Defence Program Investment: A User's Guide

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ABSTRACT

This document is a user guide for the software product, the Project Scheduling Tool (version 1.4). The tool implements various mathematical Integer Linear Programming models, as well as an approach that visualises and compares model solutions. The scheduler is 'packaged' with public software to allow required calculations to be completely automated and results to be captured in both tabular and graphical form.

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Executive Summary

Defence decision-makers are faced with the problem of scheduling and allocating funds to sustain the capability priorities identified by the organisation. Subsequently, an integrated Defence Capability Plan (DCP) is then prepared based on these capability development directions. The DCP is a living document influenced by a range of domestic and international factors. It contains projects and sub-projects which have a large number of interdependencies between their milestones. Any change to the DCP or a desire to find potential savings in the early years of the planning horizon brings about a rescheduling requirement.

This may be viewed as a complex, multi-criteria decision problem that is amenable to balance of investment mathematical approaches directed at maintaining capability interdependences. Our mathematical programming approach is designed and implemented as a scheduling tool using public software to allow the required calculations to be completely automated. A typical analysis and numerical experiment are demonstrated with general guidelines to consider when using the scheduler software.

The Scheduler is a software product which has the capability to conduct the following studies:

- What is the maximum funding saving that can be achieved without violating any constraints?

- What is a less disruptive reschedule of the current investment program that achieves almost the maximum saving found above?

- How does one obtain other reschedules that meet various levels of funding saving with minimum changes?

- How can various proposed schedules be compared and visualised in both tabular and graphical form?

- How can the results be captured at any stage and export to other tools for different analysis types?

The User guide provides help to minimise possible trouble by stating the actions that must be followed in using the scheduler. Implementing these actions will ensure that the scheduler will function as expected.

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1   Introduction

The Project Scheduling Tool which, is comprised of mathematical models implementation and results visualisation & comparison, has been created as a practical companion to the technical paper titled *An Approach for Maintaining Capability Interdependencies and Budgeting Program Investment* [10]. The technical paper presents a mathematical Integer Linear Programming (ILP) technique used in Project Management, whereas the tool provides the opportunity to implement its proposed mathematical models for project scheduling & investment problems and to numerically solve them with various decision goals as well as to visualise and compare its found solutions.

The Scheduler is a software product which has the capability to conduct the following studies:

- What is the maximum funding saving that can be achieved without violating any constraints?

- What is a less disruptive reschedule of the current investment program that achieves almost the maximum saving found above?

- How does one obtain other reschedules that meet various levels of funding saving with minimum changes?

- How can various proposed schedules be compared and visualised in both tabular and graphical form?

- How can the results be captured at any stage and export to other tools for different analysis types?

Noticeably, determining an optimal solution to this funding allocation scheduling problem has features in common with the knapsack problem [14, page 468]. The knapsack problem involves maximising the benefit from the contents of a knapsack, given a range of possible items that can be selected. Each item has a defined benefit and weight, while the knapsack itself has a total weight limit. There are extensions of this basic knapsack model in [1, 5, 13] and references therein.

Here the Defence capability interdependency and funding allocation scheduling problem involves *minimising the total number of funding changes to the current program investment* of some Defence capability projects, while meeting budget guidance and maintaining the capability interdependency requirements. The Defence problem has an additional temporal dimension which is not present in the knapsack problem. In the knapsack problem, a resource is selected and used once in a given time period. However, in the funding allocation scheduling problem, the resource has been funded for multiple years. The Defence model also differs from the above by the nature of the objective functions and the proposed multi-stages analysis.

The Norwegian Defence Research Establishment developed a stochastic model for this type of problem by considering the uncertainty of future-year budgets [4]. In our problem, project funding profiles are given and maximising funding saving is one of the decision goals. Therefore, we can restrict ourselves here to the deterministic model,

with discounted costs to cover an effect of variation on the budget. Our data structures for collection and model formulation are thus simple to implement. A decision support tool with model variation, result visualisation and comparison is also developed.

Our previous work on a similar scheduling problem for Defence Logistics Funding [9] also developed a decision support tool. The project scheduling tool, by contrast differs from the past work by incorporating capability interdependencies and various analysis features within a single program.

The free, open-source Integrated Development Environment (IDE) NetBeans [11] was used in the creation of the Graphical User Interface (GUI) for the tool. The external mathematical programming solver GLPK [8] and the Statistical Package R [6] are the main engines for solving mathematical models and analysing results. As with any piece of software, there may be bugs remaining in the code. To date the program has not been coded by professional programmers and has not undergone extensive verification and validation; it has been developed only for demonstration purpose.

The scheduler was designed for use by people who have a knowledge of the methodologies being used; and it is expected that they are familiar with the accompanying paper [10]. Our intention is not to release this software into the Public Domain, but to provide support to DSTO colleagues or Defence staff who might need it.

The documentation also provides help to minimise possible trouble by stating the actions that must be followed in using the scheduler. Implementing these actions will ensure that the scheduler will function as expected .

2   Getting Started

2.1   Installation of the Project Scheduling Tool
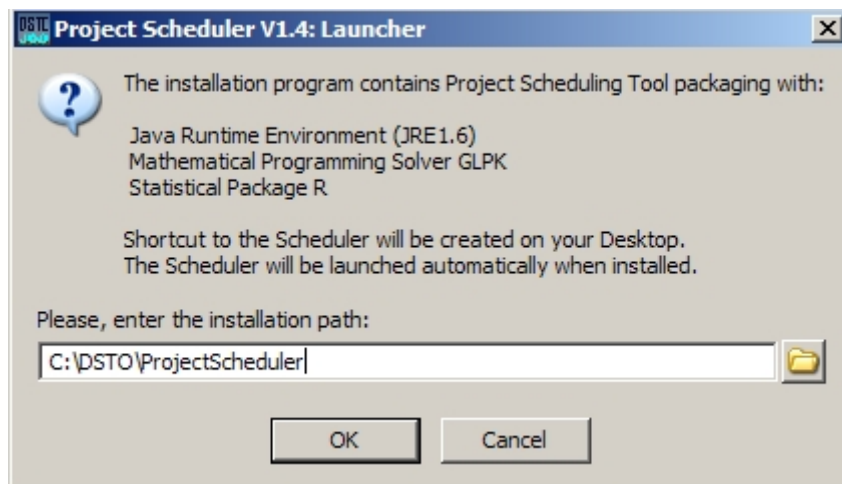

Figure 1: Installation of the Project Scheduling Tool

To install the Project Scheduling Tool[1], follow the steps below:

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[1]This User guide refers to the installation of version 1.4 of Project Scheduling Tool released on May 2014.

1. Download the zip file[2] ProjectScheduler.zip.

2. Unzip it to get the executable file ProjectScheduler.exe.

3. Double-click the executable file to start the installation process. The screen shown in Figure 1 is displayed in which the user can enter the installation path if another location is required.

4. Click the OK button. The tool will be extracted to the specified directory and automatically launched shortly.

2.2 Packaging external tools and Java Runtime Environment (JRE)

Notably, the two external tools, the mathematical programming solver GLPK [8] and the Statistical Package R [6] have been packaged into the above installation program.

Also a JRE 1.6 (or higher version) is used for running the tool. For compatibility, it is included in this installation program. Newer JRE versions can be downloaded from http://www.oracle.com/us/downloads/index.html.

3   Exploring Model Data

This section of the document aims to guide the user to perform an update of the model data. The scheduler provides a full sample set of the model data, and the user can immediately run and test the tool. To create and update the model data, go to the directory Installation_Path\files\input and replace the required Comma-Separated Values (CSV) files.

If one wanted to use the data source from Program Viewer [12] (a visualisation approach for information integration of projects and capabilities, from a number of different perspectives), then an extract data module can be set up and linked to Program Viewer for generating all CSV files automatically (see [7] for the detail of such a set-up).

Alternately, a manual process for data collection can be done as described below. There are currently six categories of data implemented.

3.1   Project Milestones

All projects data are stored in the DCP.csv file. As the tool lists the projects in the Defence Capability Plan (DCP) [3] and Defence Capability Guide[3] (DCG) [2], the data in DCP.csv file contains the following project milestone dates: (1) First Pass Approval (FPA);

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[2]The exact location of the file on the DSTO Community Portal can be obtained by contacting M.-T. Nguyen, minh-tuan.nguyen@dsto.defence.gov.au.

[3]the DCG is a new document and provides general guidance for industry on projects for the six year period following the four years Forward Estimates (FE) period of the DCP.

(2) Year Of Decision (YOD); (3) Initial Operational Capability (IOC) and (4) Final Operational Capability (FOC). The date value is the number of years counting from the study/analysis year. For example, if the requested analysis year is 2014 and the YOD of Project n is 2024, then we record $YOD_n = 10$. Below is the sample of DCP.csv file content:

Listing 1: Sample data in DCP.csv

```
Id , Project ,FPA,YOD,IOC ,FOC, Remarks
1 ,P01 ,1 ,2 ,11 ,12 , xxx
2 ,P02 ,1 ,2 ,5 ,6 , xxx
```

Listing 1 shows here two DCP project records named P01 and P02 with the same FPA and YOD, but different IOC and FOC. These projects are assigned to the index 1 and 2, respectively, for cross-referencing in other data sets.

3.2   Asset Milestones

Asset data, e.g. Key Defence Asset (KDA) is managed by Defence Materiel Organisation (DMO), and is stored in the DMO.csv file. One of the important milestones of the KDA is the Planned Withdrawal Date (PWD). The date value is counted from the study/analysis year.

Listing 2: Sample data in DMO.csv

```
Id , Asset ,PWD
1 ,A01 ,1
2 ,A02 ,9
```

3.3   Funding Data

A multi-year estimated funding given profile of all projects is placed in the funding.csv file. Note that the Project Identification (prjId) in funding.csv file is linked to the index value (Id) in DCP.csv file to give its project name and all project milestones. The Year Index (yearId) is counted as 1 if it is the study/analysis year.

Listing 3: Sample data in funding.csv

```
Id , prjId , yearId , funding
1 ,1 ,1 ,101.029141
2 ,1 ,2 ,100.890908
```

Together with the funding data, a derived first funded year needs to be recorded in the fs.csv file.

Listing 4: Sample data in fs.csv

```
prjId , funStart
1 ,1
2 ,2
```

3.4 Project Quarantine

Some projects may, for various reasons, be deemed critical, and thus their funding, and milestones must remain unchanged or be delayed at most to a limited number of years. These quarantined projects and their maximum number of slipped years are placed in the quarantine.csv file.

Listing 5: Sample data in quarantine.csv

```
Id , prjId , moveYear
1 ,1 ,0
2 ,2 ,3
```

Listing 5 shows Project 1 is untouchable while Project 2 is allowed to delay up to 3 years (assumed from all its required milestones).

3.5 Project Interdependencies

The tool currently implements seven types of scheduling interdependencies between both projects and assets and includes

- *Replacement* – a project realising a capability that is to replace an existing asset. Two files IOC-PWD.csv and FOC-PWD.csv record this interdependency type.

- *Requirement* - a decision on one project must be taken before a decision on another project. Two files YOD-YOD.csv and YOD-FPA.csv record this interdependency type.

- *Pre-requisite* - a capability realised by one project must be in service before a decision on another project. Two files IOC-YOD.csv and IOC-FPA.csv record this interdependency type.

- *Staggering* - a capability realised by one project must be in service before a capability realised by another project. This interdependency type is stored in IOC-IOC.csv file.

For example, if the FOC-PWD.csv file is shown in Listing 6, then its first record indicates that FOC_{18} of DCP Project 18 will not exceed PWD_{42} of dependent KDA 42.

Listing 6: Sample data of Replacement Type

```
Id , PrjId , AssetId
1 ,18 ,42
2 ,1 ,6
```

Similarly, if the IOC-YOD.csv file (pre-requisite interdependency type) is shown in Listing 7, then its first record indicates that IOC_2 of DCP Project 2 will not exceed YOD_4 of DCP Project 4.

Listing 7: Sample data of Other Types

```
Id , PrjId1 , PrjId2
1 ,2 ,4
2 ,6 ,7
```

3.6   Violation Fix

To allow the possibility of removing the violation of some of the interdependencies, one has to open the seven files with their names in the format fixXXX-XXX.csv (where XXX-XXX is one of seven interdependency types listed in Section 3.5 and add the identification number (depID) of all violation fixes required (see a sample data in Listing 8).

Listing 8: Sample data in Violation Fix Files

```
Id , depId
1 ,2
2 ,6
```

Notice that the last three data categories can also be modified at the runtime (i.e. during the tool running).

4   Exploring the Scheduler Environment

When the scheduling tool is launched, the default values of parameters are displayed as in Figure 2. This section of the document guides the user through the functionality of the tool.
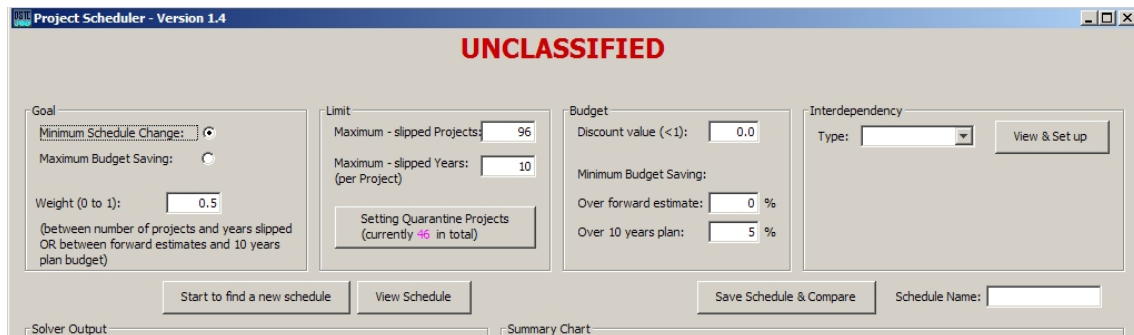
Figure 2: Project Scheduler Main Top Screen

4.1   Goal Panel

The Goal panel of the Scheduler allows the user to switch between two options[4]:

1. searching a less disruptive schedule *(minimum schedule change)* or

2. finding the *maximum budget saving* in the current project investment.

Figure 3:   Goal Options with Weighting Parameters

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[4]There are two built-in mathematical models (directB.mod and directC.mod) implemented and stored at the Installation_Path directory using GLPK modelling language [8].

Searching a less disruptive schedule (Option 1) is directed by a weighting factor (value from 0 to 1) that imposes the importance between the number of projects slipped and the total years slipped. The weight is set to 0.5 (equally important) by default for the initial experiment.

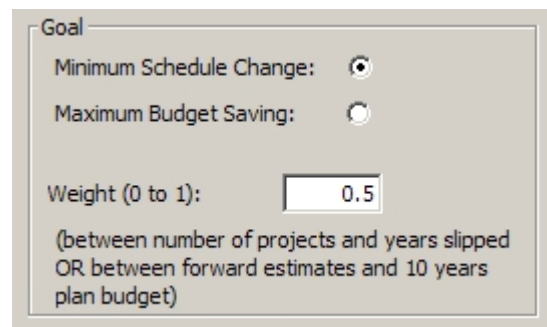In Option 2 (maximum budget saving), the weighting will be applied to adjust the importance between the 4-years forward estimates (FE) and the 10-years budget plan. The weight is set to 1 by default to count only the 10-years budget plan and ignore the FE saving.

4.2   Limit Panel

The maximum number of projects slipped and the maximum years slipped for each project are set in this panel. The special quarantine projects (see Section 3.4) can be viewed, and their maximum number of slipped years can also be modified when clicking the Setting Quarantine Projects button (Figure 5).

Figure 4: Setting Project/Year Slipped and Project Quarantine

ID	Project Name	FPA	YOD	IOC	FPA	Remark	Funding at	Max Slipped by
1	P01	2014	2015	2024	2025	xxx	2014	0
2	P02	2014	2015	2018	2019	xxx	2015	0
3	P03	2014	2015	2022	2023	xxx	2017	0
4	P04	2014	2015	2018	2019	xxx	2015	10
5	P05	2014	2015	2018	2019	xxx	2014	10
6	P06	2017	2018	2023	2024	xxx	2014	10
7	P07	2017	2018	2022	2023	xxx	2014	10
8	P08	2017	2018	2020	2021	xxx	2014	10
9	P09	2017	2018	2026	2027	xxx	2014	0
10	P10	2017	2018	2025	2026	xxx	2014	0
11	P11	2017	2018	2022	2023	xxx	2014	10
12	P12	2018	2019	2021	2022	xxx	2016	0
13	P13	2018	2019	2020	2021	xxx	2016	10
14	P14	2018	2019	2025	2026	xxx	2014	0
15	P15	2018	2019	2021	2022	xxx	2014	10
16	P16	2018	2019	2022	2023	xxx	2014	10
17	P17	2022	2023	2028	2029	xxx	2014	0
18	P18	2018	2019	2027	2028	xxx	2014	10
19	P19	2019	2020	2028	2029	xxx	2014	10
20	P20	2019	2020	2026	2027	xxx	2014	10

Quarantine Project(s) by assigning value 0 or less than 10 in the column 'Max Slipped by'

Figure 5: List of Quarantine Projects

4.3   Budget Panel

The Budget panel allows the user to set:

- the discount factor to apply the funding in each year. For example, the value 0.1 of the discount factor means $1.00 today will be $0.9 next year,

- the percentage saving level of the 10-years budget guidance, and

- the percentage saving level of the 4-years forward estimates.

4.4   Interdependency Panel

All interdependency types listed in Section 3.5 (also in Section 3.6) are accessed from this panel when selecting a particular type and clicking the ⎡View & Set up⎤ button. Figure 8 shows the interdependency pairs where it is possible to select the violation(s) to be fixed.

Figure 6: Setting Discount Factor and Saving Percentages

Figure 7: Viewing and Fixing Violations

ID	Project1	YOD1	Project2	YOD2	Violated	Fix
1	P17	2023	P18	2019	Yes	☐
2	P10	2018	P12	2019	No	☐
3	P12	2019	P17	2023	No	☐
4	P18	2019	P19	2020	No	☐
5	P01	2015	P30	2016	No	☐
6	P39	2022	P40	2022	No	☐
7	P60	2016	P68	2017	No	☐
8	P68	2017	P70	2017	No	☐
9	P72	2017	P90	2023	No	☐
10	P90	2023	P92	2023	No	☐

Figure 8: List of Interdependency Pairs with Fixing Option

4.5   Finding & Viewing a New Schedule

Once all options and parameters are set in the above panel, clicking the `Start to find new schedule` button (see the bottom left buttons of Figure 2) will activate the GLPK solver [8] to search for a schedule. The `Solver Output` panel will then display a status of the search.

If one is found from the search, the solution detail of the modified schedule can be accessed by clicking the `View Schedule` button.

4.6   Saving & Comparing Schedules

To save a schedule for comparison or accessing later, first give it a name in the text box (see bottom right side in of Figure 2) then click the `Save Schedule & Compare` button. The `Summary Chart` panel will then display a radar chart (produced by the Statistical Package R [6]) which includes all schedules saved in the running session of the tool. We will detail these features of the tool in Section 5.

4.7   Exit Program

To exit the program, click the `Close` icon at the top right corner of the main tool window (see Figure 2). Please note there is no prompt to save the current analysis when closing the tool, so you need to name and save the found schedule if you want to access it later.

5   Typical Analyis Using the Scheduling Tool

The installation program of the tool includes all model data samples and it is ready to carry out the illustrative example below. In our illustration, there are 96 Projects, 49 assets, 30 interdependency conditions of various types and 46 quarantined projects [5].

A typical analysis using the scheduler can be conducted in the various runs, as follows.

5.1   Maximum Budget Saving (*Max–Save*)

The *Max–Save* problem finds the maximum funding saving that can be achieved without violating any constraints.

Launch the scheduler and follow the steps below:

1. Select `Maximum Budget Saving` option in the `Goal` panel, also keep the default weighting value of 1 (i.e. saving goal in 10-years plan budget, see Section 4.1). All other panels remain untouched.

---

[5]Note that all data presented here is fictitious and used for illustrative purposes only.

2. Click the ⌜Start to find new schedule⌟ button. The Solver Output panel will then display a message

```
Number of Projects slipped to right: 45
Number of Projects untouched: 51
Number of Projects slipped to left: 0
Total of years slipped to right: 402
Total of years slipped to left: 0

Total Current funding: 28058.491484
Total new funding: 12907.243348
Saving: 53.998798%

Current forward estimate funding: 11979.841908
New forward estimate funding: 4523.633225
Saving: 62.239625%
```

3. Click the ⌜View Schedule⌟ button. The new window opens and displays the schedule detail as shown in Figure 9.

ID	Project Name	Slipped by
1	P01	0
2	P02	0
3	P03	0
4	P04	8
5	P05	9
6	P06	9
7	P07	9
8	P08	9
9	P09	0
10	P10	0
11	P11	9
12	P12	0
13	P13	7
14	P14	0
15	P15	9
16	P16	9
17	P17	0
18	P18	0
19	P19	9
20	P20	9

New Schedule: Schedule 1 - Version 1.4

UNCLASSIFIED

Close

Figure 9: *New Schedule Displayed*

4. Enter *"Max-Save"* in the Schedule Name text box

5. Now click the ⌜Save Schedule & Compare⌟ button. A message confirming the schedule with the entered name has been saved into the user working directory (see Figure 10).
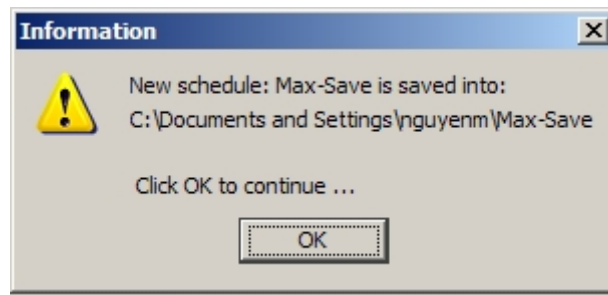
Figure 10: Saving Confirmation and New Schedule Location

6. Click the OK button to display the summary of the new schedule, *Max–Save*, in a tabular form (Figure 11). Note that the new schedule is listed together with the current schedule, *Status Quo* (i.e. no reschedule).

Schedule	Budget Saving(%)	FE Saving(%)	Projects Delayed	Years Delayed	Interp. Violated
Status Quo	0	0	0	0	6
Max-Save	53.999	62.24	45	402	5

Figure 11: New Schedule in Tabular Form

At the same time, a graphical form of the schedules summary appears at the Summary Chart panel in the main screen.
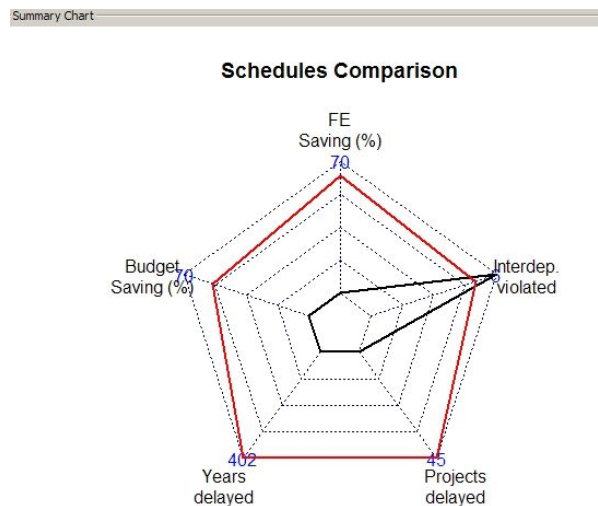

Figure 12:   New Schedule in Graphical Form
(Max-Save in Red - Status Quo in Black)

5.2   Less Disruptive Schedule (*Min–Max*)

The *Min–Max* searches for a less disruptive reschedule of the current investment program that achieves almost the maximum saving found above.

We follow similar steps as in Section 5.1.

1. Select Minimum Schedule Change option in the Goal panel, also keep the default weighting value of 0.5 (i.e. equally important between number of projects and total years slipped).

   Also, enter 50 into the Over 10 years plan box at the Budget panel. All other panels remain untouched.

2. Click the Start to find new schedule button. The Solver Output panel then displays a message from the solver. Note that the budget saving is nearly matched to the enter value 50. However, the number of projects slipped and number of years are both reduced to 22 and 197 (compared to 45 and 402 in Max–Save study), respectively.

   ```
   Number of Projects slipped to right: 22
   Number of Projects untouched: 74
   Number of Projects slipped to left: 0
   Total of years slipped to right: 197
   Total of years slipped to left: 0

   Total Current funding: 28058.491484
   Total new funding: 14023.623974
   Saving: 50.020036%

   Current forward estimate funding: 11979.841908
   New forward estimate funding: 5219.656623
   Saving: 56.429670%
   ```

3. Click the View Schedule button to see the detail of the new schedule, if necessary.

4. Enter ″Min–Max″ in the Schedule Name text box.

5. Now click the Save Schedule & Compare button.

6. Click the OK button to display the summary of the new schedule, Min–Max (Figure 13 and Figure 14).

Schedule	Budget Saving(%)	FE Saving(%)	Projects Delayed	Years Delayed	Interp. Violated
Status Quo	0	0	0	0	6
Max-Save	53.999	62.24	45	402	5
Min-Max	50.02	56.43	22	197	5

Figure 13: Schedule Comparison in Tabular Form
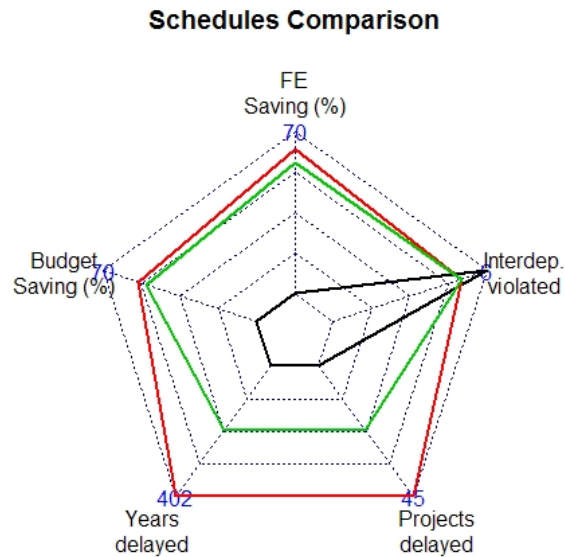
Schedules Comparison

Figure 14: *Schedule Comparison in Graphical Form (Min-Max in Green)*

5.3   Schedule with a Saving Target (*Save*– %)

Save–% allows the user to obtain a reschedule that meets various levels (in %) of funding saving with minimum changes. For this illustrative purpose, carry out *Save–15* where 15% is the funding saving on the 4-years FE period.

1. Select `Minimum Schedule Change` option in the `Goal` panel.

   Also, enter 15 into the `Over forward estimate` box and reset the `Over 10 years plan` box value to 0 at the `Budget` panel. All other panels remain untouched.

2. Click the `Start to find new schedule` button. The `Solver Output` panel then displays a message below.

   ```
   Number of Projects slipped to right: 1
   Number of Projects untouched: 95
   Number of Projects slipped to left: 0
   Total of years slipped to right: 4
   Total of years slipped to left: 0

   Total Current funding: 28058.491484
   Total new funding: 26741.154987
   Saving: 4.694966%

   Current forward estimate funding: 11979.841908
   New forward estimate funding: 10116.607013
   Saving: 15.553084%
   ```

3. Click the `View Schedule` button to see the detail of the new schedule, if necessary.

4. Enter "*Save–15*" in the `Schedule Name` text box

5. Now click the `Save Schedule & Compare` button.

6. Click the `OK` button to display the summary of the new schedule, *Save–15* (Figure 15 and Figure 16).

Schedule	Budget Saving(%)	FE Saving(%)	Projects Delayed	Years Delayed	Interp. Violated
Status Quo	0	0	0	0	6
Max-Save	53.999	62.24	45	402	5
Min-Max	50.02	56.43	22	197	5
Save-15	4.695	15.553	1	4	5

Figure 15: New Schedule Save–15 in Tabular Form
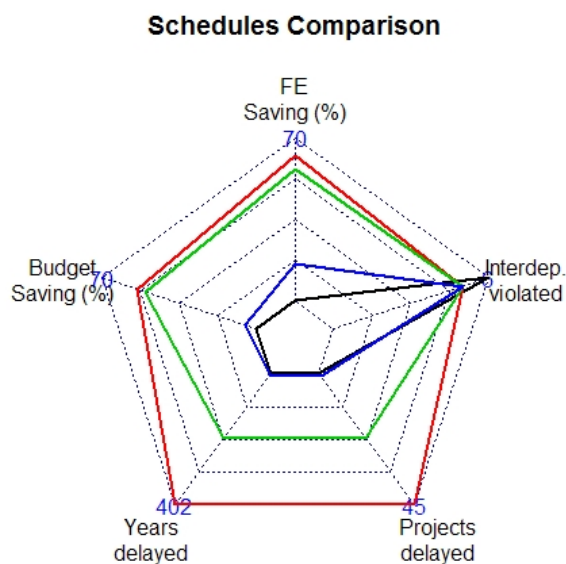

Figure 16: Schedule Comparison in Graphical Form (Save–15 in Blue)

5.4   Capturing and Exporting Schedules to Other Environments

All data and schedule results (e.g. in Figure 9) can be captured by

1. first selecting (highlighting the data) and then

2. copying into the clipboard using the standard short-cut `Ctrl+C`

3. next open any other program environment (e.g. Microsoft Excel)

4. exporting data from the stored clipboard using the standard short-cut `Ctrl+V`

Manual data analysis (e.g. Sorting, formatting) can be carried out in the new environment.

6   Summary

This document has described how to access the mathematical models and update its model data in the Project Scheduling Tool. The typical analysis through using the proposed models in the scheduler has been also illustrated step by step.

Together with this user manual and the companion technical paper on the proposed scheduling approach, this tool provides a resource for the conduct of project investment analysis. However, by itself the tool will not perform this analysis. Trained staff should still be used to interpret the inputs and the results of the model.

As with any piece of software and due to its nascent state there may be bugs remaining in the program.

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19. ABSTRACT This document is a user guide for the software product, the Project Scheduling Tool (version 1.4). The tool implements various mathematical Integer Linear Programming models, as well as an approach that visualises and compares model solutions. The scheduler is 'packaged' with public software to allow required calculations to be completely automated and results to be captured in both tabular and graphical form.			