A COMPARATIVE STUDY ON RESOURCE LEVELING CAPABILITIES OF COMMERCIAL PROJECT MANAGEMENT SOFTWARE PACKAGES FOR PROJECTS WITH RESOURCE CONSTRAINTS

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
ATILIM UNIVERSITY

NOOR HUSSEIN FAROOQ ALBAYATI

A MASTER OF SCIENCE THESIS
IN
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ABSTRACT

A COMPARATIVE STUDY ON RESOURCE LEVELING CAPABILITIES OF COMMERCIAL PROJECT MANAGEMENT SOFTWARE PACKAGES FOR PROJECTS WITH RESOURCE CONSTRAINTS

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In construction project management the critical path method (CPM) is the most commonly used technique for project scheduling. Although this technique provides many advantages for project managers, it cannot efficiently deal with the allocation of the resources. Therefore, other techniques have been introduced to address resource allocation requirements of the projects. Of these techniques, Resource Leveling aims to minimize the fluctuation in resource usage histograms obtained by CPM without violating the resource constraints, while securing the shortest CPM duration. Resource leveling is vital for effective utilization of project resources (e.g., manpower, machinery, and equipment) as it helps precluding intermittent usage of the resources. Keeping the resource usage at a relatively constant level would result in a decrease in the overall project cost as the additional costs required to demobilize and remobilize the resources will be minimized. The main objective of this study is to analyze effectiveness and efficiency of the most widely used commercial project management software packages in solving resource leveling problems with constrained resources. To this end, the most recent versions – as per the date of this study – of three software packages, namely, Microsoft Project Professional 2019, Primavera P6 Professional 2019, and Asta Powerproject version 15.0.01.489 are examined. The performance of the practiced software are evaluated based on thirteen different priority rules over a set of problem instances available in the literature. The practiced problems include 640

instances providing a diverse combination of network complexity, activity number, and resource type number. Results obtained by the software are also compared with the solutions provided by the Serial Scheduling Scheme – a heuristic method. The findings of the leveling process reveal while all the three software packages manage to provide comparable results, Asta PowerProject transpire to be the all-round best performing method while Primavera sports the fastest leveling module. This study also sheds light on the challenges and practical hurdles to utilization of the aforementioned software for resource leveling purposes.

Keywords: Resource Leveling Problem, Resource Constrained Scheduling, Project Management Software, Serial Scheduling Scheme.

ÖZ

KAYNAK KISITLI PROJELER İÇİN TİCARİ PROJE YÖNETİMİ YAZILIM PAKETLERİNİN KAYNAK DENGELEME ETKİNLİKLERİ ÜZERİNE KARŞILAŞTIRMALI BİR ÇALIŞMA

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Şubat 2021, 150 sayfa

Kritik yol yöntemi (KYY) yaygın olarak inşaat yapım projelerinin düzenlenmesinde kullanılmaktadır. KYY kullanılmasının proje yöneticileri için birçok avantajı olmasına rağmen bu yöntem kaynaklar açısından en optimal çözümü sunmamaktadır. Bu sebeple kaynak düzenleme problemini daha iyi bir şekilde çözmek için başka teknikler geliştirilmiştir. Bu tekniklerden biri de Kaynak Dengeleme Problemi'dir (KDP). Bu yöntemin hedefi KYY ile elde edilen sonuçların kaynak çizelgesini en iyi şekilde düzenlemektir. Kaynak dengelenmesi, kullanılan kaynakların (örneğin işgücü, makine ve ekipman) verimli bir şekilde kullanılması, Kaynak kullanımının nispeten sabit bir seviyede tutulması, kaynakların hareketsiz hale getirilmesi ve yeniden harekete geçirilmesi için gereken ek maliyetler en aza indirileceğinden, genel proje maliyetinde bir düşüşe neden olacaktır. Kısıtlı kaynaklarla kaynak dengeleme problemlerinin çözümünde en çok kullanılan ticari proje yönetimi yazılım paketlerinin etkililiğini ve verimliliğini incelemektir. Bu amaçla, Microsoft Project Professional 2019, Primavera P6 Professional 2019 ve Asta Powerproject sürüm 15.0.01.489 olmak üzere üç yazılım paketinin – bu çalışmanın tarihi itibariyle – en son sürümleri incelenmiştir. Uygulanan yazılımın performansı, literatürde bulunan bir dizi problem üzerinden on üç farklı öncelik kuralına göre değerlendirilmiştir. Uygulanan problemler, ağ karmaşıklığı, aktivite numarası ve kaynak tipi numarasının çeşitli bir kombinasyonunu sağlayan 640 örneği içerir. Yazılım tarafından elde edilen sonuçlar, sezgisel bir yöntem olan Seri

Planlama Şeması tarafından sağlanan çözümlerle de karşılaştırılmıştır. Kaynak dengeleme sürecinin bulguları, üç yazılım paketinin tümü karşılaştırılabilir sonuçlar sağlamayı başarırken, Primavera en hızlı dengeleme modülü sergilerken Asta PowerProject en iyi çok yönlü performans metodu göstermektedir. Bu çalışma aynı zamanda yukarıda bahsi geçen programlarının kaynak dengeleme amacıyla kullanımının önündeki zorluklara ve pratik engellere ışık tutmaktadır.

Anahtar Kelimeler: Kaynak Dengeleme Problemi, Kaynak Kısıtlı Çizelgeleme, Proje Yönetimi Yazılımları, Seri Planlama Şeması.

Dedicated to my parents ...

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

ABSDEV	Absolute Deviation Metric
Asc.	Ascending
B&B	Branch and Bound
B&K	Burgess and Killebrew Algorithm
CI	Complexity Index
CPM	Critical Path Method
CPU	Central Processing Unit
Desc.	Descending
DOS	Disk Operating System
DSS	Decision Support System
DUR	Duration
ES	Early Start Time
ES-A	Early Start Ascending
ES-D	Early Start Descending
FS	Finish to Start
GA	Genetic Algorithm
GB	Gigabyte
GHz	Gigahertz
ID	Identity
ID-A	Activity ID Ascending
ID-D	Activity ID Descending

LF	Late Finish Time
LF-A	Late Finish Ascending
LF-D	Late Finish Descending
MRD	Maximum Daily Resource Demand
MSP	Microsoft Project
NP-HARD	Non-deterministic Polynomial Time Hard
OS	Order Strength
OVERLOAD	Overload Resource Metric
PACK	Packing Method
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PSA	Particle Swarm Algorithm
PSPLIB	Project Scheduling Problem Library
R8.3	Release 8.3
RAM	Random Access Memory
RCPSP	Resource Constrained Project Scheduling Problem
RC	Resource Constrainedness
Res	Resource
RF	Resource Factor
RID	Resource Idle Days
RLP	Resource Leveling Problem
RS	Resource Strength
SA	Simulated Annealing
Sec.	Second

SD	Start Date
SSQR	Sum of Squares Metric
TCTP	Time-Cost Trade-off Problem
TF	Total Float
TF-A	Total Float Ascending
TF-D	Total Float Descending
US	United States of America

CHAPTER 1

INTRODUCTION

The term project can be defined as a unique process, consisting of a series of organized and managed tasks with start and finish dates, conducted to accomplish a goal that satisfies particular criteria, including time, cost, and resource constraints.

According to ISO10006 [1], each project must have certain characteristics which can be summarized as follows

- Special non-repetitive stages are composed of processes and activities;
- Anticipated to achieve specified quality results under preset parameters;
- Have planned start/finish dates, under explicitly defined limits of costs and resources.

Since the late 1950s, there has been an evolving need to handle different projects at various locations. Besides, due to the increase in the project's complexity, the project management (PM) techniques have been intensively used. In the 1960s, the Project Management Institute (PMI) was developed in the United States of America for promoting PM. In 1979 the International Association for Project Management was officially set up. PM is a relatively new strategy that aims to accomplish planned works within a specific budget and duration with the optimal use of resources through a good management system. PM is a crucial contribution to the development process.

PM process comprises three levels, planning, scheduling, and controlling. At the planning level, the activities that must be performed to achieve the project target and its specifications are determined such as duration, resource requirements, relationships, and constraints. During the scheduling phase, the real project schedule is formed, which involves the starting and/or finishing dates of the tasks.

Finally, the control phase concentrates on analyzing and assessing solutions when changes in the initial schedule exists.

Resources are commonly classified into two classes: renewable resources and non-renewable resources. The difference between the two main categories of resources is shown in Figure 1.1. Non-renewable resources refer to consumable resources, such as money, fuel, energy, and raw materials. The objective is minimizing the total utilization value of non-renewable resources in the available range of project durations. In contrast with the non-renewable resources, renewable resources like manpower, machines, and various other capital equipment are necessary for the execution of the project [2].

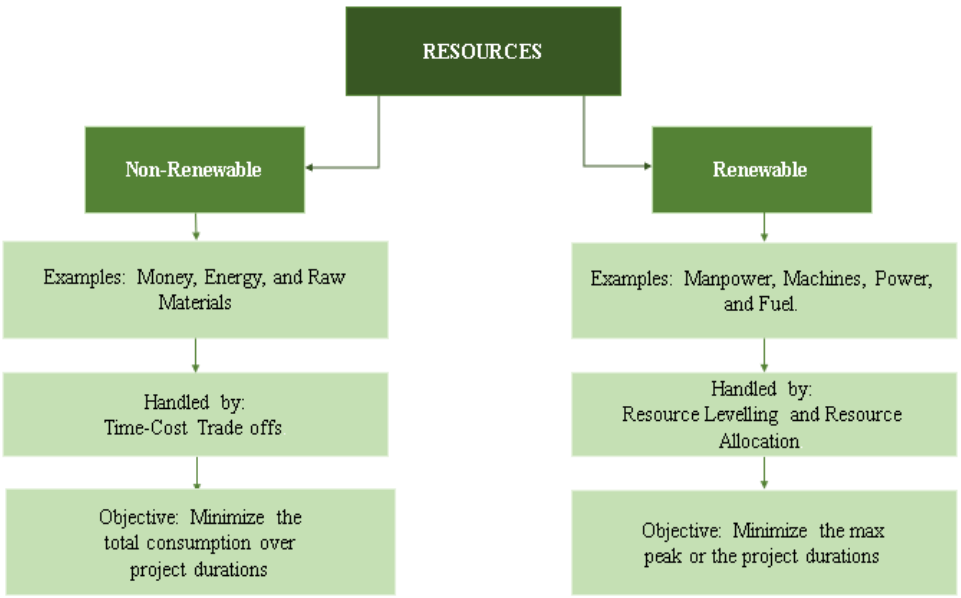

Figure 1.1 Resource types

In construction projects, the Critical Path Method (CPM) suggested by Kelley and Walker, [3] and the Program Evaluation and Review Technique (PERT) introduced by Malcolm et al. [4] have been used widely for planning and controlling the projects. The CPM/PERT has been used for helping project managers to schedule the activities of the projects to complete within a limited time and budget. CPM provides important information, such as the critical paths, free float, and total float, which are important for efficient scheduling. Generally, these network techniques assume that each activity

starts as early as possible and all needed resources for the execution of the project are unlimited. However, in real project conditions, resources are not unlimited. Accordingly, planning without considering the limitations of resource quantities provides unreliable schedules [5]. Several techniques have been proposed in the project management literature for optimization of the results of classical CPM method. Usually, these techniques could be classified into three main categories as follows.

1.1 Time-Cost Trade-Off Problem (TCTP)

Time-cost trade-off focuses on both time and cost parameters. For this type of problem, the amount of non-renewable resources is assumed to be proportional to the duration of the project. This technique is used to achieve one of the three objectives: first, to minimize project overall costs with keeping the duration fixed (deadline problem), minimize the project duration without exceeding the determined budget of the project (budget problem), and make the time–cost profile over the feasible project durations (time–cost curve problem). It is a strongly non-deterministic polynomial-time hard (NP-hard) optimization problem [6].

1.2 Resource Constrained Project Scheduling Problem (RCPSP)

The objective of the RCPSP technique is to minimize the duration by taking into consideration the precedence relationships between the activities and the limitation of the available resources required to complete the project [7, 8]. RCPSP too is considered as an NP-hard optimization problem [9].

1.3 Resource Leveling Problem (RLP)

Although, the construction projects involve different types of renewable resources there are a few studies that have been considered the impact of this type of resource on the scheduling process. The RLP minimizes the variability in the resource usage profile and maximizes the efficiency of resource usage over time by considering the available resources as unlimited with prescribed duration [10]. Project managers needs to utilize the available resources efficiently because in real projects the resource availability is limited. For that reason, the problem is also considered with limited available resources which causes an extension of the overall project duration. RL objective is to reduce the total cost since it minimizes the fluctuation in resource levels

which affects the hiring and firing percentage in a short period, and making the daily resource demands as smooth as possible [11]. The RL is considered a combinatorial non-deterministic polynomial-time (NP-hard) problem and the complexity of solving the problem increases substantially as the size of the network increases [12].

Despite a plethora of the studies in the literature use the terminologies given in sections 1.2 and 1.3 for distinguishing the two distinct yet similar resource optimization problems, A Guide to the Project Management Body of Knowledge [13] uses an alternative classification. According to PMBOK, the two resource optimization techniques are described as follows:

> *Resource leveling: "A technique in which start and finish dates are adjusted based on resource constraints with the goal of balancing demand for resources with the available supply. Resource leveling can be used when resources are only available at certain times, or in limited quantities, or over-allocated, or to keep resource usage at a constant level. Resource leveling can often cause the original critical path to change, usually to increase."*

> *Resource Smoothing: "A technique that adjusts the activities of a schedule model such that the requirements for resources on the project do not exceed certain predefined resource limits. In resource smoothing, as opposed to resource leveling, the project's critical path is not changed and the completion date may not be delayed. In other words, activities may only be delayed within their free and total float."*

The definition given for Resource Leveling in PMBOK appears to be in line with the definition of RCPSP described in section 1.2 and the explanation made for Resource Smoothing in PMBOK turns out to be in agreement with RLP defined in section 1.3. On the other hand, both RCPSP and RLP features of all the software packages practiced in this study are grouped under resource leveling. As a result, in order to avoid confusion between the apparently contradicting terminologies, resource leveling will simply be used hereafter to refer to resource leveling with resource constraints in this thesis.

Several algorithms for solving resource leveling have been proposed in the literature. The proposed algorithms fall into either of the three main categories of Exact, Heuristic, and Metaheuristic optimization methods. A summary of the related studies in the existing literature is explained in Chapter 2. In addition to the algorithms proposed in the literature, commercial project management software packages such as Microsoft Project, Primavera P6, and Asta PowerProject also incorporate features for resource leveling purposes. Due to the widespread use of such programs by the planners also because of the ease of access to the resource leveling modules of these software, motivated the author if this thesis to carry out a comparative study on the leveling performance of the aforestated software.

Resultantly, this study aims to analyze effectiveness and efficiency of the most widely used commercial project management software packages in solving resource leveling problems with constraint resources. To this end, the most recent versions – as per the date of this study – of three software packages, namely, Microsoft Project Professional 2019, Primavera P6 Professional 2019, and Asta Powerproject version 15.0.01.489 are examined. The performance of the practiced software are evaluated and guidelines are provided for the project managers for selection of the right software packages for their real-life project. Selecting the suitable tool is crucial because real-life projects include a massive number of activities and resources which makes the leveling process quite complicated.

The remainder of this thesis is organized as follows. Chapter 2 represents a brief review of resource leveling techniques, followed by studies based on resource allocation capabilities of commercial project management software packages. Chapter 3 covers the explanations about the adopted instances, and how they have been originally generated. This chapter also covers the objective functions practiced, following the problem set conversion and the leveling steps. Chapter 4 presents the results of the leveling duration, following by the average deviation results. In Chapter 5 conclusions are outlined and suggestions are pointed out for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter Overview

This chapter introduces a thorough summary of the history of RLP. It covers methods for solving this optimization problem as well as the most important algorithms related to RL have been presented here. Several Exact, Heuristic, and Metaheuristic methods have been discussed. Moreover, this chapter provides an overview of performance evaluations of earlier optimization software packages in solving RLP.

2.2 Resource Leveling Techniques

In a construction project, the planner usually tries to schedule the project as early as possible which causes fluctuation in daily resource usage histogram. If such fluctuations are not reduced, several problems will arise in the project such as intermittent employment of the staff which causes loss in productivity of the crew and reduction of the opportunity to employ skilled staff for the project, when permanent jobs cannot be provided [14]. In addition, keeping the resource usage at a relatively constant level would result in a decrease in the overall project cost as the additional costs required to demobilize and remobilize the resources will be minimized. Hence, leveling the resources is vital in the planning phase in order to reduce the effect of unleveled resources on the project budget. Therefore, this problem is considered as one of the most important aspects of project management. In the literature, the techniques proposed for resource leveling have been classified into two main groups as follows:

- Exact methods
- Heuristic and Metaheuristic methods

2.2.1 Exact Methods

The number of the studies related to implementing the exact method in RLP are limited mainly due to their high computational costs and development efforts. Of the exact methods, dynamic programming, implicit enumeration, branch and bound algorithm (B&B), and linear integer programming are observed to be more frequently implemented for solution of RL problems. In this section, a background on the exact methods proposed for solving RLP will be presented.

The first contribution to the exact method for solving RLP came from Petrovic [15] who presented a multistage approach of dynamic programming algorithm. Another early study related to the exact algorithms was presented by Mason and Moodie [16] in which a branch and bound algorithm was presented. This study focused on cost minimization and resource utilization at the same time. In this study, the extension of the project duration is accepted but delays and the resource demands exceeding the maximum available resources have been eliminated by using the cost function. To test the proposed B&B algorithm an example with a 25-activity network was used. A lower bound strategy was used to decide about the best solution and to eliminate the other over-allocated schedules.

Easa [17], proposed a linear integer programming model for optimally solving RLP. Small and medium sized instances were used in this study to evaluate the performance of the algorithm. The model formulation was based on CPM and is applicable of unraveling activity-on-arrow, activity-on-node, and the networks with single or multiple critical paths. The objective of this model was set as to make the absolute deviations (ABSDEV) as minimum as possible between the real and desirable demands of resources. The results showed that the application of this model for the practical purpose could be a challenge because of the difficulties in defining the problem requirements like the high number of variables as well as the constraints. Karshenas and Haber [18] also presented an integer linear programming based model that aims to minimize the sum of the cost of the used resources and the duration of the project. This formulation considers the time as a resource and the project duration as a variable. Two simple examples were used in this study to test the algorithm and the

results showed that the duration of the project was optimal and the costs of resource usage were low. The authors also discussed the reasons as to why the other scheduling techniques are incapable of giving the optimum solution for cost objective.

Shah et al. [19], studied a linear integer programming model to estimate the minimum resources required to complete a project. Bandelloni et al. [20], presented a new approach of optimization in resource leveling based on a dynamic non-serial programming model. The model was applied to activity-on-node networks and only showed the results if the input was scheduled by CPM. The minimization of ABSDEV was used as an objective function. The results indicated that this formulation requires less computation time and storage compared with an integer-linear programming model.

Younis and Saad [21], developed a mathematical model with the ability to handle projects with a single or multi-resource. The formulation facilitated minimizing the total ABSDEV and the difference between successive resource levels. The authors used an example consisting of 5 activities with 3 types of resources and they were able to locate the optimal solution for this problem

Mattila and Abraham [22], adopted the linear integer programming model to find the best RLP solution for linear projects such as construction of highway projects, pipeline construction projects, high-rise buildings, etc. The ABSDEV minimization was used as the objective function in this study. The model was implemented by using a software package named LINDO. The authors also discussed the hardship of achieving the objectives of large-scale projects because of the high number of constraints and variables required for defining the problem.

Neumann and Zimmermann [23], used branch and bound and truncated branch and bound to find the optimal value for the RLP. Various exact and heuristic methods were suggested for solution of RLP and Net Present Value Problem (NPVP). In this study, the minimization of the deviation of resource levels, resource costs, and deviation on the consecutive periods were used as objective functions with or without resource constraints. Instances with the number of activities 10 to 500 and 1 to 5 resource types

were used for testing the proposed B&B methods. Results revealed that the problems having up to 20 activities and 5 resource types were solved to optimality.

Son and Mattila [24], proposed a linear programming method. In this study, binary decision variables were used to level the resources with allowing to split the activities (stop and restart some of the activities) for the first time in the literature. The formulation was tested and developed on the CPM and RLP was studied by incorporating three assumptions as: activities can split; only some of the activities can split; all the activities are allowed to split. The best solution was found for the case in which all the activities were allowed to stop and restart. The model also was compared with the commercial software packages (SureTrak 3.0 and Primavera P3 3.0) running on their default settings and the proposed model was shown to provide better solutions.

Mutlu [25], developed another branch and bound algorithm for solving the RLP for single and multi-resources. The results of the 20 instance problems showed that the algorithm can find the best solution for the problem with up to 20 activities and 4 resources. Four different objective functions were used in this study including ABSDEV, the sum of squares (SSQR), daily resource demand, and weighted resource idle days. The algorithm contributed two points to the literature, namely, improvement of a new lower bound method (maximum daily allowable resources method) for finding the optimal solution for the RLP and obtaining the optimal solutions for small-size projects.

Gather et al. [26], introduced a new combination between enumeration scheme and branch and bound algorithm to solve RLP. A large number of instances with up to 20 activities presented by Kolisch et al. [27] were solved optimally for the first time. It is indicated that the mixed-integer linear programming model could be appropriate for optimal solution of RLP. In this vein, Rieck et al. [28] also presented a mixed-integer linear programming model and domain-reducing preprocessing techniques for RL problem. Sum of squares and overload objective functions were used in this study. The introduced algorithm was prepared by using an optimization software package called CPLEX 12.1. Medium-size instance problems and problem sets of Kolisch et al. [27] were used to test the performance of their method. The problems with up to 30

activities and 5 resource types were solved optimally. Furthermore, instances with 50 activities with 5 resource types were solved for the first time in the literature.

Ponz-Tienda et al. [10], proposed a parallel branch and bound algorithm for RLP. 50 instance problems with minimal lags were used for evaluation purposes. The new exact algorithm was shown to find the optimal solution for the practiced instances. Furthermore, a comparison was made between the Adaptive Genetic Algorithm (AGA) and the parallel branch and bound algorithm. The authors state that this algorithm can also be applied for RCPSP.

2.2.2 Heuristic and Metaheuristic Methods

Heuristic models are generally simple methods formulated for solving optimization problems. They are mostly problem-solving techniques for developing a successful step-by-step solution or for improving the current solution with different trials of adjusting problem parameters. Moreover, metaheuristic models have independent strategies that can be applied to a different number of optimization problems. They are more complicated methods compared with the heuristic models, but they are generally stronger when it comes to solving more complex problems. Examples of metaheuristic approaches are Genetic Algorithm, Particle Swarm Optimization, Ant Colony, Simulated Annealing, etc.

The earliest study related to the heuristic method in solving RLP had been introduced by Burgess and Killebrew [29]. This study presented a new heuristic method for the resource leveling problem. This method aimed to make the objective function as minimum as possible by changing the start date of the non-critical activities with respect to a pre-defined priority. In this study SSQR was used as the objective function.

Harris [30], developed an alternative heuristic algorithm based on the critical path method for resource leveling by minimizing the moment in resource usage profile called Packing method (Pack) which was named after pack containers. The algorithm built the histogram step by step until all the activities were positioned in a CPM or PERT network while satisfying the constraints. The heuristic considered the minimum resource requirement of critical activities to generate resource usage curves. Then the

resource requirement for non-critical activities was added to the base histogram as small packages. Therefore, the final resource utilization histogram shape was rectangular. Martinez and Ioannou [31] and Hiyassat [32] also studied the pack method with modification on minimizing the moment in resource usage profiles. The researchers proposed a modification on the minimum moment approach presented by Harris [33]. The modified model could shift the activity to a better position. Therefore. The developed model reduces the calculations compared with the traditional model. On the other hand, the results showed a little difference between the modified and traditional models. Nevertheless, the two models had no ability to find the optimal minimum moment because the algorithm treated each activity as an independent activity.

Nevertheless, Hiyassat [34] developed a modified minimum moment technique to solve RLP for multiple resource types. The implementation of the integrated model achieved relatively the same results as the traditional model. Though, in certain examples, the results were much better than the traditional model. Christodoulou et al. [35], developed yet another Pack-based method and a minimum moment method for RLP. The modification was done by making allowances for extension or shortening of activity durations. The authors suggested that the resource leveling of the activities should be modified in order to achieve better resource usage profiles while considering maximum daily resource requirements.

Savin et al. [36], introduced a Neural Network (NN) based method for solving the RLP instead of the priority based methods. The model has been developed by mapping an augmented Lagrangian multiplier (ALM) optimization formulation of a resource leveling problem (RLP) onto a discrete-time Hopfield net. Moreover, Kartam and Tongthong [37], developed an Artificial Neural Networks (ANN) for solving resource leveling problem (RLP). This paper presents a powerful and unique approach compared to the traditional heuristic and optimizing resource leveling (RL) techniques. The Resource Leveling Artificial Neural Network (RLANN) utilizes the advantages of the Hopfield and competition-based artificial neural networks. The RLANN is applicable to networks produced by Critical Path Method (CPM) either arrow or precedence diagram forms. The scheme consists of two layers, an input and a

competition layer. Solving methods within the RLANN are depended on an equation of motion and a competition technique to control the daily utilization of resources. The technique is clear and can be applied either on a private computer or on a parallel control unit. The solutions presented are equal or better than those provided by the other heuristic techniques.

In the last few years, meta-heuristic algorithms have been developed for solving RLP such as Genetic algorithms. There have been numerous studies focusing on the implementation of GA for resource leveling problems. One of the earliest studies presented by Chan et al. [38], described an improved genetic algorithm known as PAVENET-R for RLP and RCPSP. The authors used two standard examples in this study. Both of the problems consisted of 11 activities with one or two resource types. The proposed algorithm aimed to minimize fluctuations between resource availability and utilization without an exponential increase in computational time even for instances with larger networks. Hegazy [39], also used a GA-based technique to find a near-optimal solution. Random priorities were studied for chosen activities and their effect on the schedule was discussed. The instances used in this study consisted of 20 activities with 6 resource types. The GA-based technique produced a project with shorter duration and better leveled resource usage histograms.

Leu et al. [40], used genetic algorithm and the decision support system (DSS) model to find the optimal solution for the RLP. The developed algorithm provided the optimal or near-optimal solutions for projects with multiple resources; additionally, start and finish dates were included as an objective of resource leveling. In this paper, an example with 9 activities and 3 resource types was used. The results showed great flexibility compared to other heuristic models. Zheng [41], proposed a GA combined with multi objective function for solving multi resources leveling problems. The suggested algorithm treats each resource as an independent resource. A simple example consisting of 6 activities and two resource types was used. The results indicated that the developed model was practical yet provides the optimal solution. Another GA-based algorithm was introduced by Senouci and Eldin [42] for solving the total cost optimization problems that incorporated precedence relations among the activities.

El-Rayes and Jun [14], used genetic algorithms for RLP and suggested two new optimization metrics: resource idle days (RID) and maximum daily resource demand (MRD) as objective functions. The first metric measures the total number of resources that must have been released throughout low requirement periods and hired back in the later stages of the project during the high requirement periods. The second metric calculates the total idle number and nonproductive days for resources caused by undesirable fluctuation in resource usage. The suggested metrics are intended to minimize the fluctuations and peak resource usage simultaneously. The researchers used an example with 20 activities and one resource type to evaluate the algorithm. Doulabi et al. [43], proposed a hybrid genetic algorithm for multi-resource leveling of large-scale projects with repair mechanisms. This algorithm benefitted from the possibility of splitting some of the activities. To test the algorithm benchmark problems were generated with a number of activities of up to 2,000 for small instances, and for comparison purposes large networks of up to 5,000 activities. The developed algorithm solved the problems of the multi resources at a reasonable time and improved the index of resources leveling by about 76%. Roca et al. [44] and Jun and El-Rayes [45] used GA for solving RLP and RCPSP at the same time. Iranagh and Sonmez [46], developed a genetic algorithm for RLP and made performance comparisons between GA and Microsoft Project 2010. The authors used the absolute deviation (ABSDEV) between available resources and resource requirements as the objective function. 16 problems with number of activities ranging from 5 to 20 and a single resource type were used in this study. The results showed that GA was able to solve 8 of 16 problems with ABSDEV of 4%, and MS project solved only one of 16 problems with ABSDEV of 44%.

The more recent study on metaheuristic algorithms was presented by Ponz-Tienda et al. [12]. The authors introduced an adaptive genetic algorithm with Weibull distribution to calculate global optima and to terminate the procedure. A 1440-instance problem sets with a number of activities of up to 120 which were taken from the Project Scheduling Problem Library (PSPLIB) were used to test the algorithm.

There also exist several other metaheuristic algorithms studied for RLP such as the one proposed by Neumann and Zimmermann [47]. The authors developed a

metaheuristic method called a polynomial priority-based algorithm for RLP and RCPSP. They used different objective functions to test the proposed algorithm. A detailed performance evaluation was studied for problem instances with up to 500 activities with number of resources up to five. The results indicate that the proposed method can be successful in solving problems within a reasonable computation time.

Another meta-heuristic method was introduced by Colorni et al. [48], named as ant colony algorithm. This method was inspired by ant colonies which each ant performs very basic actions and does not know directly what other ants are really doing. They combined the autocatalytic method – which by itself aims to converge to a sub-optimal direction with exponential speed – with the greedy force – which by itself is incapable of finding anything except a sub-optimal path. In doing so, the authors have been able to introduce an extremely organized behavior to the colony. Moreover, Xiong and Kuang [49], proposed a Serial Schedule Generation Scheme (SSGS) with Ant Colony Optimization (ACO) algorithm to solve RLP. An example with 13 activities and one resource type generated by Son and Skibniewski [50], was implemented in the study. Results indicated that the proposed models can produce acceptable solution even for complex networks. Geng et al. [51], developed a Directional Ant Colony Optimization (DACO) algorithm for solving nonlinear resource leveling problems. The activity-on-node-based DACO technique is shown to be effective and efficient in dealing with premature convergence or poor exploitation, and it has an advantage of not translating the real data into code compared with genetic algorithms. Simple random exploitation is carried out in the ACO approach, while the DACO algorithm is designed to search for a promising path in the area considered. It is a directional search that combines a globally optimized trail, the local best path and random exploitation for resource-leveling optimization which can improve the performance of the traditional ACO approach. The DACO algorithm not only can perform global exploration efficiently and rapidly, but also can improve the solution quality significantly.

On the other hand, Particle Swarm Optimization (PSO) technique is also used for solving resource leveling problems. A study introduced by Qi et al. [52], proposed an improved particle swarm optimization (IPSO) algorithm to solve RLP. Firstly, a mapping was created between the feasible schedule and the location of the particle, the

IPSO then started to seek the best global and the best local solutions until the stopping criteria was met. A case study has been presented and a comparison is made between IPSO and some traditional algorithms. The findings show that the results of IPSO are better than the heuristic techniques and is agued to sufficiently provide practical usage for resource leveling problems. Pang et al. [53], proposed a discrete nonlinear mixed integer optimization model and an improved particle swarm optimization method. Constriction factor was introduced to PSO to control flying speed of particles and to enhance local search ability of this algorithm. Nevertheless, this optimization technique is only suited to the optimization of a single resource. In reality, many types of resources are included in the schedules, such as various materials, construction equipment, and so on. Guo et al. [54], developed a mathematic model for multiple-resources leveling in multiple projects scheduling problem and adopted particle swarm optimization to solve the problem. Then two test examples were studied, by comparing the best solution obtained by PSO with that obtained by GA. Finally, they presented that their PSO-based method is successful at solving the leveling multiple resources in multiple projects scheduling problem.

Additionally, one of the recent studies, a hybrid meta-heuristic method is introduced by Alsayegh and Hariga [55]. A combination of particle swarm optimization (PSO) and simulated annealing (SA) is generated. The authors considered the multi resource leveling problem (RLP) with the ability to split the non-critical activities for minimizing the total cost of the project. Six hybrid PSO-SA search procedures were designed, each of them involving a different mechanism. A set of 180 benchmark problems was generated to evaluate the time and cost performance of the six algorithms. The developed algorithm proved to find the near-optimal solution for the projects in less computation time compared to an exact method.

2.3 Previous studies based on Resource Allocation Capabilities of Commercial Project Management Software Packages

Johnson [56], studied the performance of commercial software for solving RCPSP. 110 instance examples with number of activities ranging from 7 to 15 and resources types from 1 to 3 were used. The capabilities of seven different software packages

were tested, including Super Project 1.0 and 2.0, Timeline 2.0 and 4.0, Primavera 4.00, 4.1 and 5.0, Harvard Total Project Manager II, Harvard Project Manager 3, Hornet, Pertmaster, Microsoft Project 1.0 and 3.0. The best performance was found to be for Timeline 2.0 and the worst performance was noted for Microsoft Project 1.0.

Maroto and Tormos [57], studied the performance of different software packages in solving RCPSP. A single instance problem consisting of 51 activities and three resource types was used for evaluation purposes. The researchers used seven different software packages of CA-Super Project 2.00A, Insta Plan 3.00B, Micro Planner for Windows 6.24A, Micro Planner Professional 7.3B, Microsoft Project for Windows 1.0, Microsoft Project for Windows 3.0, and Project Scheduler 1.0. The best solution was reported for CA-Super Project and Microsoft Project 3.0 and the worst solution was recorded for the Microsoft Project 1.0.

Kolisch et al. [27], used seven project management software packages for RCPSP too. The authors used a set of 160 instance problems generated by ProGen and ProGen/max. The number of activities was listed as 10, 20, and 30 with 1 to 3 resource types. A comparison was made among seven software packages including Artemis Schedule Publisher 4.1, CA-Super Project 3.0C, Microsoft Project 4.0, Primavera Project Planner 1.0, Project Manager Workbench 1.1.02w, Project Scheduler 6.0 1.02, and TimeLine 6.0.0. The best solution was found to be of Timeline 6.0.0 and the worst performing software was discovered to be Artemis Schedule Publisher 4.1.

Mellentien and Trautmann [58], evaluated the performance of five commercial software packages in solving the RCPSP. Acos Plus.1 8.2, CA-SuperProject 5.0A, CS Project Professional 3.0, Microsoft Project 2000, Scitor Project Scheduler 8.0.1 were tested. A set of 1,560 instance problems were used with 30, 60 and 120 number of activities and 4 resource types. The best solutions were found by Scitor Project Scheduler 8.0.1 and Acos Plus.1 8.2.

Hekimoglu [59], studied the performance of Primavera Enterprise Project Management 4.1 (using two priority rules of minimum total slack and late finish time) and Microsoft Project 2003 software packages for RSCP. The author used a set of

2,040 instance problems with 30, 60, 90, and 120 number of activities and 4 resource types. The results showed that for small problems Microsoft Project was performing better than Primavera, and for large problems Primavera using late finish time priority was recommended.

Kastor and Sirakoulis [5], discussed the RCPSP capabilities of three software packages of Primavera P6.0, Microsoft Project 2007, and Open Workbench 1.1.6. The authors used two real construction project examples. The first one consisted of 98 activities with one resource type and the second included 668 activities with 7 resource types. The results revealed better performance by Primavera P6.0 [5].

Cekmece [60], used Primavera Enterprise Project Management P6.0- and Microsoft Project 2007 software packages for RSCP. 45- instance problems used with 30, 60, and 120 number of activities that included 4 resource types. In this study P6.0 provided better results than Microsoft Project 2007. Furthermore, the author argued Hekimoglu [59] preferring Microsoft Project to Primavera over the small projects was not justifiable since they both provided relatively the same results.

Son and Mattila [24], proposed a linear programming method and compared the results with the capabilities of two commercial software packages of SureTrak Project Manager 3.0 and Primavera Project Planner P3.0 for solving the resource leveling problem. Binary decision variables were used to level the resources with allowing to split the activities (stop and restart some of the activities) for the first time in the literature. The formulation was tested and developed on the CPM and RLP was studied by incorporating three assumptions as: activities can split; only some of the activities can split; all the activities are allowed to split. Two examples were used consisting of 10 and 11 activities and one resource type and the best solution was found for the case in which all the activities were allowed to stop and restart

Iranagh and Sonmez [46], made a comparison between the performance of Microsoft Project 2010 and genetic algorithm solution of RLP. A set of 16 problems having up to 21 activities and a single resource was used. The results of resource leveling

revealed superiority of the performance of the proposed genetic algorithm over Microsoft Project 2010.

Rezvan Khan [61], made a comparison among Primavera P6.0 Professional R8.3, Microsoft Project Professional 2013, and Asta PowerProject V.12.5 software packages for RLP. A set of 640 instance problems were used for this purpose with 50, 100, 200, and 500 number of activities including 1, 5, 10, and 15 resource types. The results of the practiced software were compared with those obtained by Burgess and Killebrew heuristic method [29]. The author discussed Burgess and Killebrew's algorithm required less computational time to solve the problems. They even indicated that the heuristic method was able to provide better solutions than the resource leveling module of the experimented software.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Chapter Overview

This chapter will cover the explanations about the instances adopted for this study and how they have originally been generated. This chapter will also provide practical information as to how should the data be imported to the different software packages. Objective functions will be discussed as well as the related formulation. The experimented software packages together with the Serial Scheduling Scheme algorithm will be elucidated herein. Moreover, the assumption of the daily available resource value and leveling process will be clarified.

3.2 Resource Leveling Problem Sets

In order to evaluate the resource leveling capabilities of project management software packages, 640 instances that were originally generated by Rezvan Khan [64] by using RanGen instance generator have also been used in this thesis. The researcher preferred RanGen to ProGen and ProGen/Max instance generators because of the ability to choose various parameters for generating a problem set [62]. In addition, RanGen is capable of generating samples with more complicated networks that can resemble complexity of real-life projects. The parameters considered in the instance generation process included: number of activities, topology indicator or network complexity (Order Strength (OS)), resource factor (RF), resource constrainedness (RC), and resource strength (RS). What follows is a brief explanation on how the original instances were generated by Rezvan Khah [64?] and how they were slightly modified.

3.2.1 Activity Number

This parameter defines the number of activities used in generating the problem set instances. Four levels of 50, 100, 200, and 500 activities are used in this study.

3.2.2 Topology Indicator / Network Complexity

Is an index that represents the network complexity named Order Strength (OS). Plainly, it is a parameter used to measure and set the number of precedence relationships in the network. Larger OS values indicate network activities are expected to include higher number of precedence relationships. Four levels of 0.1, 0.3, 0.5, and 0.7 are used for each problem set in this study.

3.2.3 Resource Factor (RF)

The resource factor represents the average fraction of the resource type required per each activity. It can also be regarded as an index displaying the ratio of the resources used.

3.2.4 Resource Constrainedness (RC)

The Resource Constrainedness parameter defines the demand for each of the resources. Resource demand per each resource increases from 0 to maximum available number as RC is increased from 0 to 1 for that specific resource. Resultantly, the value of RC is set as 0.9 for every resource type to generate more complex problems.

3.2.5 Resource Strength (RS)

This parameter regulates resource availability. RS ratio ranges from 0 to 1 and larger values suggest greater resource availability. In the original study by Rezvan Khah [61], it is indicated that this parameter has not been considered while generation of the instances since in resource leveling the demand for each resource is decided by the user. Though, in this thesis the values resulting from this parameter have been modified which is elucidated in section 3.2.6.

3.2.6 Problem Set Generation

As discussed earlier in section 3.2.5, in the original study by Rezvan Khah [61], the RS parameter has not been considered while generation of the instances. As a result of this, the resource availabilities defined by RanGen for each resource in each instance have been set randomly without making any presumptions about their permissible ranges. For instance, in most of the sample problems the resource availabilities have been set randomly with values as high as 100, or sometimes even larger values are defined. Such large resource availabilities not only lack practical relevance, but also effectively remove the constraindness of the resources. On the other hand, for each resource type, setting resource availability amount less than the largest daily utilization value of an activity would have increased the original duration of that specific activity during the leveling process. More specifically, the largest daily utilization value for any resource type is defined as 10 for any of the original instances generated; that is, setting any value smaller than 10 for the resource availability would have caused leveling to extend the original duration of the activities for the sake of satisfying the constraints on the number of the available resources. Since in this study the results of the software packages are intended to be compared with those of Serial Scheduling Scheme – in which activity durations remain unchanged – any potential changes in the original activity durations are precluded in the leveling processes by equalizing the values of resource availability and daily utilization. For these very reasons, in order to adapt the original instances for resource leveling with resource constraints, some minor modifications are introduced herein as resource availability of 10 is assumed for each and every resource for all the instances.

All the instances were originally generated in text format. An example problem is represented partially in Figure 3.1. Figure 3.2 explains the arrangement of the data within the generated text documents. As seen in Figure 3.2, the first row represents the number of the activities, right to which the number of resource types is written. The second row shows the availability of each type of resource which – as discussed earlier – are all set to be equal to 10. The next rows represent the information of the problem arranged as follows: The first column displays the duration of the activities in days; the second column represents daily usage for the first resource type and similarly (n+1)th column represents daily usage for the nth resource type;; the column next to

the availability of *n*th resource shows the number of successors for each activity; and the rest of the columns represent the successors of each activity. All the relationships among the activities are assumed to be Finish to Start (FS). Obviously, FS means an activity may only start when all of its preceding activities finish.

Unique names are assigned for the instances; for example, a sample named "E50 5-2-4" mean this instance includes 50 activities; has 5 resource types; has a complexity (Order Strength) of 0.3; and is the fourth sample with the said configurations. This example is represented in Figures 3.1 and 3.2. The activity number for this example appears to be 52 because of the two dummy activities (start and finish milestones). Readers are referred to Rezvan Khah [61], for further details on the instance generation procedure.

52	5															
10	10	10	10	10												
0	0	0	0	0	0	10	2	3	4	5	7	12	13	20	26	30
2	9	0	9	3	4	8	22	18	16	11	10	9	8	6		
6	5	3	4	2	4	9	51	37	36	33	27	24	23	15	14	
4	9	8	3	9	8	4	47	31	28	27						
4	0	1	3	6	3	8	51	46	39	33	29	28	23	19		
9	4	3	1	10	2	8	51	50	49	34	24	21	19	14		
9	0	3	3	6	1	9	49	48	47	35	34	33	31	21	16	
4	10	8	7	8	8	10	50	48	47	36	35	33	31	29	24	21
6	1	10	9	1	6	7	49	48	36	32	31	17	14			
6	8	10	5	8	3	7	51	50	42	36	33	29	24			
2	7	0	8	3	1	7	50	49	42	35	33	32	29			
9	2	5	8	10	0	7	47	44	40	38	37	35	25			
3	6	5	9	0	10	7	49	48	47	43	42	40	24			
5	10	4	1	6	3	6	47	46	45	42	40	29				
8	7	7	3	7	5	6	48	47	44	43	41	31				
2	1	7	8	4	1	4	45	43	42	36						
8	6	8	0	4	1	4	47	46	40	35						
8	6	7	5	9	4	4	48	47	45	35						
10	2	6	4	6	9	6	48	47	44	42	40	37				
9	0	5	4	10	5	4	49	42	35	32						
3	2	4	5	9	1	6	46	45	43	42	41	40				
8	5	3	2	5	1	4	48	46	42	40						
6	7	8	7	9	4	4	50	48	44	31						
4	10	5	8	5	1	4	46	45	44	41						
2	2	0	1	8	5	4	45	43	42	41						
8	4	10	2	6	0	4	49	47	42	41						
2	4	6	2	3	3	3	49	44	35							
2	4	1	3	7	2	2	45	32								
1	2	0	1	4	4	3	44	43	41							
10	8	6	1	5	1	3	49	43	42							
2	10	9	8	0	0	2	42	40								
3	9	8	10	0	1	2	44	40								
7	8	3	0	7	1	2	45	40								

Figure 3.1 Part of a 50-activity instance with five resource types

Activity Number							
52	Resource Types						
	5						
Each resource Availability measure (RCPSP)							
10	10	10	10	10			
Activity Duration							
0	Each resource types daily utilization value						
2	0	0	0	0	0	Number of successor	
6	9	0	9	3	4	10	Successors
4	5	3	4	2	4	8	2,3,4,5,7,12,13,20,26,30
4	9	8	3	9	8	9	22,18,16,11,10,9,8,6
9	0	1	3	6	3	4	51,37,36,33,27,24,23,15,14
9	4	3	1	10	2	8	47,31,28,27
4	0	3	3	6	1	8	51,46,39,33,29,28,23,19
6	10	8	7	8	8	9	51,50,49,34,24,21,19,14
6	1	10	9	1	6	10	49,48,47,35,34,33,31,21,16
2	8	10	5	8	3	7	50,48,47,36,35,33,31,29,24,21
9	7	0	8	3	1	7	49,48,36,32,31,17,14
3	2	5	8	10	0	7	51,50,42,36,33,29,24
5	6	5	9	0	10	7	50,49,42,35,33,32,29
8	10	4	1	6	3	7	47,44,40,38,37,35,25
2	7	7	3	7	5	6	49,48,47,43,42,40,24
8	1	7	8	4	1	6	47,46,45,42,40,29
8	6	8	0	4	1	4	48,47,44,43,41,31
10	6	7	5	9	4	4	45,43,42,36
9	2	6	4	6	9	4	47,46,40,35
3	0	5	4	10	5	6	48,47,45,35
8	2	4	5	9	1	4	48,47,44,42,40,37
6	5	3	2	5	1	6	49,42,35,32
4	7	8	7	9	4	4	46,45,43,42,41,40
2	10	5	8	5	1	4	48,46,42,40
8	2	0	1	8	5	4	50,48,44,31
2	4	10	2	6	0	4	46,45,44,41
2	4	6	2	3	3	4	45,43,42,41
1	4	1	3	7	2	3	49,47,42,41
10	2	0	1	4	4	2	49,44,35
2	8	6	1	5	1	3	45,32
3	10	9	8	0	0	3	44,43,41
7	9	8	10	0	1	2	49,43,42

Figure 3.2 Arrangement of data for a 50-activity instance with five resource types

For each problem configuration of: activity number (50, 100, 200, and 500), resource type number (1, 5, 10, and 15), and OS (0.1, 0.3, 0.5, and 0.7), 10 instances were generated totaling 640 sample problems. Tables 3.1 to 3.4 display the parameter configuration of these 640 instances divided into four groups with respect to activity numbers.

Table 3.1 50-activity problem set specifications

Activity number	Resource number	Order Strength (OS)	Number of instances
50	1	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
50	5	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
50	10	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
50	15	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10

Table 3.2 100-activity problem set specifications

Activity number	Resource number	Order Strength (OS)	Number of instances
100	1	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
100	5	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
100	10	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
100	15	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10

Table 3.3 200-activity problem set specifications

Activity number	Resource number	Order Strength (OS)	Number of instances
200	1	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
200	5	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
200	10	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
200	15	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10

Table 3.4 500-activity problem set specifications

Activity number	Resource number	Order Strength (OS)	Number of instances
500	1	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
500	5	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
500	10	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10
500	15	OS = 0.1	10
		OS = 0.3	10
		OS = 0.5	10
		OS = 0.7	10

3.2.7 Problem Set Conversion and Resource Leveling Setup

As discussed earlier in section 3.2.6, all generated instances are in text format which cannot be directly imported into any of the experimented software packages. Therefore, some adjustments must be made to re-arrange and convert the files in order to correctly input the data into the programs. In the first step, the data for each problem is imported to a Microsoft Excel file as it matches the mapping in Microsoft Project

(MSP) program. After importing the Excel sheet into MSP, the maximum units for daily usage of each resource is defined as 10 by switching the active view to Resource Sheet because the maximum value of the daily resource utilization was assumed as 10 for all resource types for the whole instances (refer to section 3.2.6). 'Level only within available slack' is unchecked on Resource Leveling pane before running the Level All option located under Level group of the Resource tab. This is done to ensure leveling will respect the constraints on the availability of the resources. Resource leveling processes are then carried out and the results recorded. After each round of leveling/recording, all resources are returned back to their original state, i.e., they are unleveled by selecting the Clear Leveling option under the same menu on the ribbon. Resources are unleveled in order to import them to the other two software packages. It is observed and verified that the data can be imported easily from MSP to Asta PowerProject either as an '.mpp' or an '.xml' file; in contrast with Primavera P6 for which resource usage and maximum unit data were not imported properly. Therefore, benefitting from an intermediate file format converter, files with '.mpp' extension are converted to '.mpx' first. Similar to the procedure explained for MSP, necessary leveling options are configured before leveling the resources. More precisely, for P6 'Level resources only within activity Total Float' is unchecked on Level Resources window and 'Extend finish' is checked on Resource Leveller window. As a result of these settings, leveling, would be able to satisfy the constrained number of resources by shifting the start times of the activities and freely extending the duration of the project. Presumably, this setting contrasts with the leveling options employed in the original study of Rezvan Khan [61], who leveled the resources without making any allowance for the changes in the completion date of the projects.

As discussed in section 4.2, objective function calculations are carried out externally by using Microsoft Excel for the leveled schedules. For this, a major bottleneck is experimented with Asta PowerProject especially for more complicated instances with higher number of work items as it takes quite significant time to export the leveled daily resource consumptions. It takes so long to either copy or export resource usage data as '.csv' files that it removes away practicality of the obtained leveled values for post-processing purposes. Though, to walk around this issue, the authors have discovered an effective yet simple technique. The leveled schedules first need to be

exported as '.mpp' files, then opened and exported as Excel files using Microsoft Project software.

3.3 Objective Functions

Two groups of objective functions will be discussed in this section. The first group explained in section 3.3.1, includes methods widely used for evaluation of the resource leveling capabilities of different approaches. Whereas, the second group, elucidated in section 3.3.2, includes the metrics frequently used for analyzing the performance of methods for resource leveling capabilities of projects with constrained resources. One per each group is exercised in this thesis to not only assess the makespan minimization capabilities, but also the leveling capabilities of the experimented leveling approaches.

3.3.1 Objective Functions for Resource Leveling

Most objective functions push the solution procedure to generate a flat resource usage histogram where variations are minimized. Nevertheless, this rectangular form of the histogram might not be feasible most of the time, and a bell-shaped resource profile may be more realistic in real construction projects. In this section, four different objective functions with the related formulations to minimize the fluctuation in resource usage histogram are explained; namely, Sum of Squares Metric (SSQR), Absolute Deviation Metric (ABSDEV), Overload Metric (OVERLOAD), and the Idle Days and Maximum Daily Resource Demand Metric (RID-MRD).

3.3.1.a Sum of Squares Metric (SSQR)

This metric minimizes the sum of squared daily resource usage where the summation involves the weights for different types of resources. This metric captures daily resources usages over or under the average resource demand. This method has the strongest capability of peak minimization compared with the absolute deviations and overload metrics. As stated in section 3.3.3, this metric has been adopted throughout the experimentations of this study. The formulation of this metric is given in Eq. (3.1).

$$f_{SSQR} = \sum_{k=1}^{K} w_k \sum_{t=1}^{T} r_{kt}^2 \tag{3.1}$$

where; f_{SSQR} is the objective function to be minimized, *K* is the total number of resource types; *k* is the resource type; w_k is the weight of resource *k*; *T* is the total project duration; *t* is a day in the project span; r_{kt} is the resource usage of resource type *k* at the day of *t.*

3.3.1.b Absolute Deviation Metric (ABSDEV)

This metric determines the absolute deviations of daily usage of resources from a target daily amount of resource usage. Generally, target daily resource usage is set as the average daily resource usage which is a fixed value for each resource type. Standard rounding is usually used for average resource demand calculations. The formulation of this metric is given in Eqs. (3.2) and (3.3).

$$f_{ABSDEV} = \sum_{k=1}^{K} w_k \sum_{t=1}^{T} |r_{kt} - y_k| \tag{3.2}$$

$$y_k = \left[\left(\frac{1}{T}\sum_{t=1}^{T} r_{kt}\right) + 0.5\right] \tag{3.3}$$

where; f_{ABSDEV} is the objective function to be minimized; *K* is the total number of resource types; *k* is the resource type; w_k is the weight of resource type *k*; *T* is the total project duration; *t* is a day in the project span; r_{kt} is the resource usage of resource type *k* at the day of *t*; and y_k is the average resource utilization level as calculated in Eq. (3.3). The addition of 0.5 in the average calculation is to ensure standard rounding before flooring operation.

3.3.1.c Overload Metric (OVERLOAD)

Leveling capabilities of this metric is quite similar to ABSDEV. The main difference between these two metrics is that the overload metric only captures the positive values of resource deviation; whereas, the ABSDEV measures both the positive and the negative deviations from the targeted resource usage. The formulation of this metric is presented in Eqs. (3.4) and (3.5).

$$f_{OVERLOAD} = \sum_{k=1}^{K} w_k \sum_{t=1}^{T} (overload_k) \tag{3.4}$$

$$\begin{cases} if\ (r_{kt} - y_k) > 0 & overload_k = (r_{kt} - y_k) \\ else & overload_k = 0 \end{cases} \tag{3.5}$$

where; $f_{OVERLOAD}$ is the objective function to be minimized; *K* is the total number of resource types; *k* is the resource type, w_k is the weight of resource type *k*, *T* is the total project duration; *t* is a day in the project span, $r_{kt}$is the resource usage of resource type *k* at the day of *t* and y_k is the average resource utilization level.

3.3.1.d Resource Idle Days and Maximum Daily Resource Demand Metric (RID-MRD)

This objective function is a combination of two metrics known as resource idle day (RID) and maximum daily resource demand (MID). This combinatorial metric was introduced by El-Rayes and Jun [14] which aims to minimize the idle days of a resource and peak resource demands of each resource in a balanced way at the same time. RID seeks to reduce idle resource days, but it has no ability to reduce the maximum resource demand. Therefore, MRD metric has been integrated with RID to minimize the maximum demand for all resources. The formulations of these two metrics given in Eqs. (3.6), (3.7), and (3.8).

$$f_{RID-MRD} = f_{RID} w_{RID} + f_{MRD} w_{MRD} \tag{3.6}$$

$$f_{RID} = \sum_{k=1}^{K} w_k \sum_{t=1}^{T} \left(min\left(max(r_{k1}, r_{k2}, \dots, r_{kt}), max(r_{kt}, r_{kt+1}, \dots, r_{kT})\right) - r_{kt} \right) \tag{3.7}$$

$$f_{MRD} = \sum_{k=1}^{K} w_k \times max(r_{k1}, r_{k2}, \dots, r_{kt}, \dots, r_{T-1}, r_{kT}) \tag{3.8}$$

where; $f_{RID\text{-}MRD}$ is the objective function to be minimized; K is the total number of resource types; k is the resource type; w_k is the weight of resource type k, T is the total project duration, t is a day in the project span, r_{kt} is the resource usage of resource type k at the day of t, w_{RID} is the weight of RID metric, w_{MRD} is the weight of MRD metric.

3.3.2 Objective Functions for Resource Constrained Project Scheduling Problem

The project schedule must be planned to represent the organization's objectives. One of the main objectives of any project is the timely completion of the project scope which is facilitated by means of proper scheduling. Meanwhile, leveling the resources generally tend to increase the makespan of the project due to shifting forward and decreasing the overlapping segments of the parallel activities requiring the same type of resources – more than its availability – at the same time. Evidently, having less fluctuations in the resource usage profiles while securing the shortest makespan is a desired outcome of the leveling process. In this vein, other sets of objective functions including but not limited to Makespan Minimization and Net Present Value are also proposed in the literature to analyze makespan minimization capabilities of different leveling approaches. These metrics are discussed in the following sections.

3.3.2.a Makespan Minimization

The minimization of the makespan of the project is a project scheduling target most widely referred to. This is achieved simply by minimizing the completion date of the very last activity in the network.

3.3.2.b Net Present Value

This function is designed to maximize the net present value of the project. Generally, schedule limits consist of the maximum and minimum lags of the start date of two separate activities. This function assumes the required resources to accomplish the project are limited.

3.3.3 Exercised Objective Functions

One per each of the two distinct objective function groups discussed in section 3.3 are practiced in this thesis to not only analyze the makespan minimization capabilities, but

also the leveling capabilities of different approaches over projects with constrained resources. From the first group, RID-MRD metric is not preferred in this study considering its relatively complicated implementation and on the grounds that keeping the balance between RID and MRD (i.e., deciding on w_{RID} and w_{MRD} weights) contain a level of subjectivity. On the other hand, Yeniocak [63] in their study concludes that Sum of Square (SSQR) metric is able to obtain better resource utilization profiles with lower maximum daily resource demands. Hence, in this thesis study, SSQR objective function is used mainly because it demonstrates the strongest capability in peak minimization of resource utilizations compared with ABSDEV and OVERLOAD metrics. It is more effective in minimizing the peaks chiefly due to squaring of the deviations, thereby penalizing the deviated utilizations even more so than the other methods. As discussed earlier, leveling the resources generally tend to increase the overall duration of the project due to shifting forward and decreasing the overlapping segments of the parallel activities requiring the same type of resources – more than its availability – at the same time. Obviously, having less fluctuations in the resource usage profiles while securing the shortest makespan is a desired outcome of the leveling process and to analyze this, Makespan Minimization metric from the second group of objective functions is employed in this thesis.

3.4 Experimented Commercial Software Packages

The suitable selection of software packages is vital since each program has their own merits and demerits. In this thesis though, resource leveling capabilities of some the more widely practiced software are addressed. This study evaluates effectiveness and efficiency of three software packages of Microsoft Project Professional 2019, Primavera P6 Professional 2019, and Asta PowerProject version 15.0.01.489 in resource leveling of projects with constrained availability of resources.

3.4.1 Microsoft Project (MSP)

This program was released in 1984 in the U.S. by Microsoft company. Microsoft Project (MSP) is a popular program providing various sets of features, such as scheduling, resource leveling, monitoring, reporting, and the latest versions provide tools for planning multiple projects, work breakdown structure, and risk analysis. It is developed to help the project manager to schedule the project easily, assigning

resources to activities, tracking the progress, analyzing workloads, and controlling the budget. It is widely used by residential builders, constructing companies with medium and small projects [64]. This program facilitates easy creation of the schedule but has difficulties in managing project progress according to the complexity of updating the schedule correctly. A few basic functions are lacking such as creating a full copy of the project, the opportunity to use calendars with various working hours for each day, and the ability to assign two relationships between the same two activities. The trial version of MSP 2019 is used in this study.

3.4.2 Primavera P6

This program was originally introduced as Eagle Ray in the 1990's in the U.S. which was later acquired by Primavera Systems and then by Oracle company. It is a very powerful tool in the hands of the project managers and efficiently helps with planning the projects, scheduling, tracking the progress, controlling, and provides enterprise portfolio management. It is mainly used in infrastructure projects and construction projects with medium and large scales [65]. The main advantage of Primavera is its ability to manage large amounts of data and its very powerful scheduling engine. At the same time, it has some disadvantages that can be summarized as the scheduled dates may contain irrelevant data as a planned schedule has progressed and the way P6 shows the scheduled dates as a baseline since no baseline has been set. Primavera has no ability to read all baseline data in the reporting of progress, and it is graphically limited which has no ability to show various non-work times in various views or to put graphics on the Gantt Chart. Therefore, it is important for an enterprise to have professional users and a manager who knows the program to ensure that the baselines are handled correctly and that they do not show irrelevant data.

3.4.3 Asta PowerProject

This program is one of the earliest project management and control programs produced in the U.K. in the 1980's. This program was developed for construction projects providing different features as to plan, schedule, and develop project. It is generally used in large construction companies [66]. The benefits of using it can be summarized as the program provides unlimited baselines, many scheduling options, multiple projects with multiple users per file, and displays multiple baselines on the Gant chart.

On the other hand, the disadvantages of the program are difficulties in finding expert people who know how to operate the program, takes a long time to learn because it offers more functions compared with the other programs, and difficulties in creating and formatting total and free floats.

3.5 Serial Scheduling Scheme (SSS)

The Serial Scheduling Scheme (SSS) is a heuristic algorithm for resource leveling of the problems with constrained resources and was first introduced by Kelly [67].SSS aims to minimize the project total duration while satisfying precedence and resource constraints. In this thesis, results obtained by the software packages are also compared with the solutions provided by this heuristic method. SSS was implemented in MATLAB 2019 and the activity ID was used as the activity leveling priority in this study. As declared earlier in section 3.2.5, for SSS too the maximum daily available resources of 10 was used for each resource type for all the instances. SSS was coded to simply administer the four steps explained below:

1. Schedule the activities according to the chosen priority which is activity ID in this case;
2. The first activity from the prioritized list of activities is selected with the condition that all of its predecessors been already scheduled;
3. The selected activity is scheduled according to its possible Earliest Start (ES) date such that both of the precedence and resource constraints are satisfied;
4. Step 2 and 3 are repeated for the next activity on the prioritized list. This process is repeated for all the activities on the list until all the activities are scheduled.

CHAPTER 4

COMPARATIVE PERFORMANCE EVALUATIONS

In this chapter, the results of the comparative study on the leveling capabilities of the latest versions – as of the date of this study – of three software discussed in sections 3.4.1 to 3.4.3, i.e., Microsoft Project Professional 2019, Primavera P6 Professional 2019, and Asta PowerProject version 15.0.01.489 will be demonstrated. Performance evaluations also involve comparisons with the results obtained by a commonly used activity-shifting-based heuristic explained in section 3.5, i.e., Serial Scheduling Scheme (SSS).

The leveling process is applied to 640 instances having up to 500 activities with up to 15 resource types. Unleveled durations of the practiced instances ranged from 16 to 2,146 days. A total of 14 different method/priority combinations – including activity ID for SSS – were experimented over an overall 14 × 640 = 8,960 leveling attempts. All of the experiments were performed on a Laptop computer running on an Intel® Core™ i7-5500 CPU at 2.40 GHz, with an operating system of 64 bit, and 12 GB of RAM.

4.1 Exercised Leveling Priorities

Leveling priority simply indicates the order of the leveling process. As illustrated in Table 4.1, 13 of the most common leveling priorities that are frequently implemented in the literature and are used in practice are exercised in this study. As seen in Table 4.1, the Standard priority is used for MSP while for Primavera P6 four different priorities with two distinct sorting orders for each of them are applied. Ascending sort order means the software will select activities with a lower number first.

For instance, Activity ID-Ascending (ID-A) priority points out that the software will first select the activity with the lowest ID number regardless of its total float or other parameters.

The contrary, in Activity ID-Descending (ID-D) priority, the software will first select the activity with the greatest ID number. Total float, Early Start (A and D), and Late Finish (A and D) priorities follow the same logic. Three single priorities with one Multi Priority are used for Asta PowerProject. The Multi Priority is the combination of three individual priorities of Activity ID, Task Start Date, and Total Float. Finally, as pointed out earlier, Activity ID priority is used for the SSS heuristic.

Table 4.1 List of priorities selected for each leveling process

Software Package	**Exercised Priority**	
	Denotation	**Explanation**
MSP 2019	S	Standard
Primavera P6	ID (Asc.)	Activity ID-Ascending
	ID (Desc.)	Activity ID-Descending
	TF (Asc.)	Total Float-Ascending
	TF (Desc.)	Total Float-Descending
	ES (Asc.)	Early Start-Ascending
	ES (Desc.)	Early Start-Descending
	LF (Asc.)	Late Finish-Ascending
	LF (Desc.)	Late Finish-Descending
Asta PowerProject	TF	Total Float
	ID	Activity ID
	TS	Task Start Date
	MP	Multi Priority
Serial Scheduling Scheme	ID	Activity ID

4.2 Objective Function Calculations

All the three commercial software packages experimented in this study report the resource usage data in man-hours per day. Thus, the SSQR objective function calculations discussed in section 3.2.7 are carried out externally by using Microsoft Excel for the leveled schedules. As the daily working hours were set as 8 hours, the outcomes were divided by 8 for all the values of the daily resource in order to make them comparable with the results of Serial Scheduling Scheme. For a case problem, the Excel sheet used for SSQR calculations is demonstrated in Table 4.2. As seen in Table 4.2, the case problem spreads over a duration of 28 days, includes 6 activities, requires 4 resource types each of which are available in 10 units per day. The total SSQR objective function is measured as 4,684 for this case problem.

Table 4.2 Example SSQR objective function calculations

Number of days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
res-1	40	40	40	40	64	64	64	64	64	64	56	56	56	56	56	56	56	56	56	0	80	80	80	80	80	80	80	80
res-2	64	64	64	64	48	48	48	48	48	48	24	24	24	24	24	24	24	24	24	0	24	24	24	24	24	24	24	24
res-3	80	80	80	80	8	8	8	8	8	8	80	80	80	80	80	80	80	80	80	0	16	16	16	16	16	16	16	16
res-4	72	72	72	72	32	32	32	32	32	32	64	64	64	64	64	64	64	64	64	0	0	0	0	0	0	0	0	0
res-1 / 8 =	5	5	5	5	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7	0	10	10	10	10	10	10	10	10
res-2 / 8 =	8	8	8	8	6	6	6	6	6	6	3	3	3	3	3	3	3	3	3	0	3	3	3	3	3	3	3	3
res-3 / 8 =	10	10	10	10	1	1	1	1	1	1	10	10	10	10	10	10	10	10	10	0	2	2	2	2	2	2	2	2
res-4 / 8 =	9	9	9	9	4	4	4	4	4	4	8	8	8	8	8	8	8	8	8	0	0	0	0	0	0	0	0	0
res-1 ^ 2 =	25	25	25	25	64	64	64	64	64	64	49	49	49	49	49	49	49	49	49	0	100	100	100	100	100	100	100	100
res-2 ^ 2 =	64	64	64	64	36	36	36	36	36	36	9	9	9	9	9	9	9	9	9	0	9	9	9	9	9	9	9	9
res-3 ^ 2 =	100	100	100	100	1	1	1	1	1	1	100	100	100	100	100	100	100	100	100	0	4	4	4	4	4	4	4	4
res-4 ^ 2 =	81	81	81	81	16	16	16	16	16	16	64	64	64	64	64	64	64	64	64	0	0	0	0	0	0	0	0	0
sum res-1 ^ 2 =	1725																											
sum res-2 ^ 2 =	625																											
sum res-3 ^ 2 =	1338																											
sum res-4 ^ 2 =	996																											
Total sum of squares=	4684																											

4.3 Computation Time for Leveling Processes

Computation times are also recorded throughout the analyses using a stopwatch. CPU times for every individual instance under each of the practiced priority schemes are measured. The author acknowledges that the CPU times reported could have some degree of measurement error due to inevitable human error, for, adopting a stopwatch for process time measurement purposes. As mentioned earlier in section 3.2.6, 10 instances for each problem configuration of: activity number (50, 100, 200, and 500), resource type number (1, 5, 10, and 15), and OS (0.1, 0.3, 0.5, and 0.7) were generated totaling 640 sample problems. Table 4.3 represents the average CPU times for each 10 similarly-configured problems. With respect to the results, Primavera P6 is experienced to be the fastest method with a total average of 1 second which is followed by MSP with a total average of 116 seconds. The solution times of the Asta PowerProject and Serial Scheduling Scheme algorithm are significantly higher compared to those of Primavera P6 and MSP. Detailed leveling processing times for each of the individual instances are tabulated in Tables A.1 to A.4 in the Appendices chapter.

Since in real-life projects the number of activities is very high and are typically more than 300 work items [68], the duration of the leveling process can play a major role and can be regarded as one of the chief deciding factors in preference of a software package in practice. The results of this study indicate that all software packages require relatively the same amount of computation time to level small-scale instances with 50 activities. For medium-scale instances including 100 to 200 activities Primavera P6 is shown to be the fastest method compared to the other approaches. For large-scale instances with 500 activities only Primavera P6 is experienced to achieve results in reasonable processing times as the other programs were significantly slow in leveling the problems.

Table 4.3 Average computation time for each problem set

Number of activities	No of resources	Avg. CPU Time (Sec.)													
		MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
		S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
50	1	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	32
	5	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	58
	10	2	1	1	1	1	1	1	1	1	16	16	11	15	72
	15	5	1	1	1	1	1	1	1	1	40	40	35	41	72
100	1	1.8	1	1	1	1	1	1	1	1	2	2	1.5	2	81
	5	6	1	1	1	1	1	1	1	1	18	18	16	18	184
	10	12	1	1	1	1	1	1	1	1	22	22	19	22	232
	15	20	1	1	1	1	1	1	1	1	31	31	26	31	249
200	1	9	1	1	1	1	1	1	1	1	19	19	10	19	244
	5	36	1	1	1	1	1	1	1	1	49	48	35	49	440
	10	76	1	1	1	1	1	1	1	1	102	99	72	102	450
	15	120	1	1	1	1	1	1	1	1	207	186	127	208	483
500	1	58	1	1	1	1	1	1	1	1	54	54	29	52	1528
	5	300	1	1	1	1	1	1	1	1	414	409	301	417	2983
	10	523	1	1	1	1	1	1	1	1	967	905	811	917	2804
	15	692	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	7875	7449	2450	7971	14822
Total average		**116**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**614**	**581**	**247**	**617**	**1546**

4.4 Leveling Performances of Experimented Approaches

Since no optimal solution is available in the literature for any of the instances used, the percent deviations from the best solutions with the smallest objective function values found – termed as Upper Bound (UB) – are used instead to evaluate the effectiveness of the software packages as well as the Serial Scheduling Scheme for solution of resource constrained leveling problems. As pointed out before, a total of 14 different method/priority combinations were experimented for each individual problem; whereof, the value for UB is decided by determining the best objective function among the 14 values calculated. After setting the UB values, deviations from UB for every leveling attempt are measured in percentages. Tables B.1 to B.4 in the Appendices chapter summarize the SSQR objective function values as well as UB's for each of the instances. In addition, in Appendix C, the performances of each commercial software package and Serial Scheduling Scheme algorithm over every individual instance is given in Tables C.1 to C.4 as percent deviations from the corresponding UB values. In the following sections, more insight will be provided on the obtained results.

4.4.1 Performance Comparisons based on Number of Activities

For performance comparisons, initially, the average percent deviations from UB are analyzed with respect to the number of project activities and inferences are made. With respect to total average deviations given in Table 4.4, Task Start Date priority used for Asta PowerProject happen to provide the best results with a deviation of 6.63% while Serial Scheduling Scheme with an average deviation of 45.39% turns out to perform the worst. For instances with 50 activities, the best solution with an average deviation of 2.62% was found by Primavera P6 when TF (Desc.) priority was used and it was followed by the rest of priorities used with the same software. When Primavera is set aside, Asta PowerProject is experienced to provide the lowest average deviation of 9.84% when TF priority is used and next in order is the solutions found by using other priorities with PowerProject. Succeeding PowerProject, MSP with an average deviation of 14.08% and Serial Scheduling Scheme with an average deviation of 25.54% are discovered to perform poorer than the first two software. For the rest of the instances with 100, 200, and 500 activities, the best solutions with the lowest

average deviations were found by PowerProject when TS priority was used. In this leveling attempt, average deviations of 4.69%, 10.66%, and 0.76% were experimented for problems including 100, 200, and 500 activities, respectively.

Table 4.4 Average deviation from UB based on activity numbers

Number of activities	No of resources	Avg. Deviation based on Activity Numbers (%)													
		MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
		S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
50	1	5.77	11.69	10.85	80.22	8.80	12.93	11.30	14.50	9.00	1.93	4.32	2.95	2.72	67.09
	5	15.36	1.87	1.60	3.16	0.71	2.79	1.71	3.81	1.20	12.63	13.76	12.58	12.97	30.99
	10	17.95	0.85	1.07	1.46	0.95	0.81	1.15	1.38	0.65	12.82	15.65	13.52	13.11	4.03
	15	17.23	0.04	0.04	0.22	0.04	0.04	0.04	0.16	0.04	12.29	15.13	12.91	12.31	0.04
Average		**14.08**	**3.61**	**3.39**	**21.27**	**2.62**	**4.14**	**3.55**	**4.96**	**2.72**	**9.92**	**12.22**	**10.49**	**10.28**	**25.54**
100	1	5.78	9.96	5.95	6.73	6.91	9.02	6.81	11.62	4.55	1.40	3.70	1.68	1.43	63.93
	5	13.07	3.45	2.14	3.42	1.68	2.76	2.57	4.01	1.63	10.79	10.57	7.82	11.28	40.50
	10	12.76	1.18	0.84	1.70	0.71	0.88	0.92	1.55	0.72	10.80	11.20	8.82	11.24	6.10
	15	129.63	102.27	102.27	103.58	102.10	102.10	102.37	102.85	102.10	13.56	14.92	0.43	13.35	103.07
Average		**40.31**	**29.21**	**27.80**	**28.86**	**27.85**	**28.69**	**28.17**	**30.00**	**27.25**	**9.14**	**10.10**	**4.69**	**9.33**	**53.40**
200	1	95.90	107.01	100.88	103.57	98.36	107.74	100.93	109.52	98.45	0.97	20.37	14.72	19.91	205.18
	5	12.05	2.32	1.28	2.42	0.99	2.15	1.51	3.11	1.03	13.39	12.28	10.62	12.59	45.90
	10	12.64	0.22	0.09	0.64	0.07	0.19	0.19	0.76	0.04	12.60	13.10	9.42	11.72	11.86
	15	12.26	0.52	0.48	0.89	0.48	0.49	0.52	0.83	0.48	11.42	10.51	7.94	11.20	1.01
Average		**33.21**	**27.52**	**25.68**	**26.88**	**24.97**	**27.64**	**25.79**	**28.55**	**25.00**	**9.60**	**14.07**	**10.67**	**13.86**	**65.99**
500	1	3.04	6.73	2.84	5.42	2.19	6.25	3.91	7.48	2.27	1.38	2.16	0.63	1.59	81.60
	5	5	32	31	33	31	32	31	33	31	4	3	1	4	38
	10	7.06	47.22	47.02	48.78	47.01	47.19	47.25	48.81	46.99	4.02	4.71	0.93	4.84	7.07
	15	5.79	40.77	40.82	44.26	40.76	40.77	41.35	43.94	40.76	3.29	4.17	0.57	4.13	4.98
Average		**5.30**	**31.72**	**30.37**	**32.81**	**30.13**	**31.51**	**30.92**	**33.42**	**30.16**	**3.11**	**3.62**	**0.76**	**3.74**	**32.98**
Total average		**23.23**	**23.02**	**21.81**	**27.45**	**21.39**	**23.00**	**22.11**	**24.24**	**21.28**	**7.94**	**10.00**	**6.65**	**9.30**	**44.48**

4.4.2 Performance Comparisons based on Number of Resource Types

Second to number of project activities, the effect of resource type numbers is also analyzed on the performance of the resource leveling approaches. Considering the total average deviations given in Table 4.5, it can clearly be observed that the number of resource types has a significant impact on the leveling performance of all the experimented leveling approaches. When results are evaluated based on the number of different resources, it is realized that Asta PowerProject with TS priority provides the best solutions with a total average deviation of 6.62%. On the other hand, SSS with a total average deviation of 47% is observed to perform the worst. For instances with a single resource type, the best solution with an average deviation of 1.41% was obtained by PowerProject when TF priority was used. For the rest of the problems with 5, 10, and 15 resource types, the best solutions with the lowest average deviations were achieved by PowerProject when TS priority was selected. In this leveling attempt, average deviations of 7.98%, 8.13%, and 5.46% were experimented for problems including 5, 10, and 15 resource types, respectively.

Table 4.5 Average deviation from UB based on resource type numbers

Number of activities	No of resources	Avg. Deviation based on Resource Type Numbers (%)													
		MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
		S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
50	**1**	5.77	11.69	10.85	80.22	8.80	12.93	11.30	14.50	9.00	1.93	4.32	2.95	2.72	67.09
100		5.78	9.96	5.95	6.73	6.91	9.02	6.81	11.62	4.55	1.40	3.70	1.68	1.43	63.93
200		95.90	107.01	100.88	103.57	98.36	107.74	100.93	109.52	98.45	0.97	20.37	14.72	19.91	205.18
500		3.04	6.73	2.84	5.42	2.19	6.25	3.91	7.48	2.27	1.38	2.16	0.63	1.59	81.60
Average		**27.62**	**33.85**	**30.13**	**48.99**	**29.07**	**33.98**	**30.74**	**35.78**	**28.57**	**1.42**	**7.64**	**4.99**	**6.41**	**104.45**
50	**5**	15.36	1.87	1.60	3.16	0.71	2.79	1.71	3.81	1.20	12.63	13.76	12.58	12.97	30.99
100		13.07	3.45	2.14	3.42	1.68	2.76	2.57	4.01	1.63	10.79	10.57	7.82	11.28	40.50
200		12.05	2.32	1.28	2.42	0.99	2.15	1.51	3.11	1.03	13.39	12.28	10.62	12.59	45.90
500		5	32	31	33	31	32	31	33	31	4	3	1	4	38
Average		**11.45**	**9.95**	**8.96**	**10.45**	**8.48**	**9.89**	**9.23**	**11.09**	**8.62**	**10.14**	**10.02**	**7.98**	**10.31**	**38.92**
50	**10**	17.95	0.85	1.07	1.46	0.95	0.81	1.15	1.38	0.65	12.82	15.65	13.52	13.11	4.03
100		12.76	1.18	0.84	1.70	0.71	0.88	0.92	1.55	0.72	10.80	11.20	8.82	11.24	6.10
200		12.64	0.22	0.09	0.64	0.07	0.19	0.19	0.76	0.04	12.60	13.10	9.42	11.72	11.86
500		7.06	47.22	47.02	48.78	47.01	47.19	47.25	48.81	46.99	4.02	4.71	0.93	4.84	7.07
Average		**12.37**	**11.88**	**11.60**	**12.60**	**11.44**	**11.79**	**11.75**	**12.72**	**11.41**	**10.08**	**10.93**	**8.13**	**10.24**	**13.60**
50	**15**	17.23	0.04	0.04	0.22	0.04	0.04	0.04	0.16	0.04	12.29	15.13	12.91	12.31	0.04
100		129.63	102.27	102.27	103.58	102.10	102.10	102.37	102.85	102.10	13.56	14.92	0.43	13.35	103.07
200		12.26	0.52	0.48	0.89	0.48	0.49	0.52	0.83	0.48	11.42	10.51	7.94	11.20	1.01
500		5.79	40.77	40.82	44.26	40.76	40.77	41.35	43.94	40.76	3.29	4.17	0.57	4.13	4.98
Average		**41.23**	**35.90**	**35.90**	**37.24**	**35.84**	**35.85**	**36.07**	**36.95**	**35.84**	**10.14**	**11.18**	**5.46**	**10.25**	**27.27**
Total average		**23.17**	**22.90**	**21.65**	**27.32**	**21.21**	**22.88**	**21.95**	**24.13**	**21.11**	**7.94**	**9.94**	**6.64**	**9.31**	**46.06**

4.4.3 Performance Comparisons based on Network Complexity (OS)

Eventually, the impact of Network Complexity (OS) on the performance of the resource leveling approaches is also evaluated. With regard to the total average deviation amounts summarized in Table 4.6, the significance of the effect of this factor on the results can too be verified. When solutions are analyzed with respect to complexity of the networks, it is concluded that Asta PowerProject when ran using TS priority achieves the best results with a total average deviation of 6.63%. Whereas, Serial Scheduling Scheme with a large total average deviation of 45.39% is experienced to provide the worst solutions. For the instances with OS factors of 0.1, 0.3, and 0.5, respectively, the best solutions with average deviation values of 3.47%, 5.09%, and 6.31%were achieved by PowerProject when TS priority was chosen. In addition, for instances with the greatest OS value of 0.7, the best solution with an average deviation of 7.74% was located by PowerProject when TF priority was selected.

Table 4.6 Average deviation from UB based on OS factor

Number of activities	OS	Avg. Deviation based on OS (%)													
		MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
		S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
50	**0.1**	14.58	4.16	4.12	5.32	2.96	4.53	4.50	5.39	3.27	8.75	12.34	9.81	9.42	25.60
100		13.28	8.67	6.83	9.65	6.39	7.25	7.71	9.75	6.38	8.26	7.73	1.90	8.51	39.24
200		6.50	0.99	0.86	1.74	0.84	0.90	1.04	1.80	0.82	7.83	6.69	2.01	5.97	17.34
500		4.13	44.03	43.42	48.15	43.28	43.88	44.52	48.03	43.29	4.43	4.01	0.17	4.62	35.17
Average		**9.62**	**14.46**	**13.81**	**16.21**	**13.37**	**14.14**	**14.44**	**16.24**	**13.44**	**7.32**	**7.69**	**3.47**	**7.13**	**29.34**
50	**0.3**	14.31	3.49	3.47	4.68	2.81	3.59	3.75	4.77	2.55	10.08	12.58	10.44	10.36	26.19
100		23.89	15.55	13.98	14.98	14.27	14.63	14.81	16.01	13.78	9.22	9.11	3.69	9.73	41.69
200		9.69	2.32	1.04	2.08	1.04	2.23	1.63	2.74	1.08	7.88	8.31	6.24	8.47	34.09
500		4.87	35.82	34.75	36.79	34.50	35.64	35.39	37.17	34.61	4.54	4.32	0.00	5.30	35.28
Average		**13.19**	**14.30**	**13.31**	**14.63**	**13.16**	**14.02**	**13.90**	**15.17**	**13.00**	**7.93**	**8.58**	**5.09**	**8.47**	**34.31**
50	**0.5**	13.39	3.34	2.89	3.60	2.48	1.20	2.85	4.73	2.69	10.55	12.17	11.05	10.93	24.04
100		49.66	36.16	34.70	35.12	35.11	36.04	34.87	36.74	34.06	11.20	12.66	5.89	11.85	61.26
200		11.33	3.08	1.58	2.93	1.34	2.90	1.58	3.76	1.25	10.17	10.27	8.53	9.97	32.74
500		6.03	27.77	26.20	28.25	25.94	27.46	26.48	29.04	25.91	3.12	4.05	0.08	4.32	33.13
Average		**20.10**	**17.59**	**16.34**	**17.48**	**16.22**	**16.90**	**16.45**	**18.57**	**15.98**	**8.76**	**9.79**	**6.39**	**9.27**	**37.79**
50	**0.7**	14.03	3.46	3.07	40.69	2.24	4.43	3.10	4.96	2.39	10.29	11.77	10.65	10.40	26.32
100		74.41	56.48	55.68	55.68	55.62	56.83	55.29	57.52	54.77	7.86	10.88	7.28	7.21	82.29
200		105.29	103.63	99.21	100.73	96.64	104.49	98.86	105.87	96.82	12.46	30.94	25.88	30.96	180.90
500		6.20	19.27	17.13	18.06	16.81	19.08	17.27	19.45	16.84	0.35	2.11	2.78	0.73	31.31
Average		**49.98**	**45.71**	**43.77**	**53.79**	**42.83**	**46.21**	**43.63**	**46.95**	**42.71**	**7.74**	**13.93**	**11.65**	**12.33**	**80.21**
Total average		**23.22**	**23.01**	**21.81**	**25.53**	**21.39**	**22.82**	**22.10**	**24.23**	**21.28**	**7.94**	**10.00**	**6.65**	**9.30**	**45.41**

4.5 Makespan Minimization Capabilities of Experimented Approaches

In order for better evaluation of resource leveling capabilities of different methods over projects with limited resources, a more holistic approach is taken as in addition to the leveling capabilities, makespan minimization abilities are also considered. As pointed out before, a total of 14 different method/priority combinations were experimented for each individual problem; whereof, the value for minimum makespan is decided by determining the shortest overall project duration among the 14 values calculated. Thence, deviations from this amount for every leveling attempt are measured in percentages. Tables D.1 to D.4 in the Appendices chapter summarize the makespan values as well as the minimum makespan for each of the instances. Table 4.7 represents the average percent deviations from minimum makespan for each 10 similarly-configured problems. When total average percent deviations from minimum levelled makespans are considered, it can be concluded that Microsoft Project 2019 is able to achieve the best results with a total average deviation of 4.63%. Whereas, Serial Scheduling Scheme with a large total average deviation of 23.14% provides the worst solutions.

Table 4.7 Average deviation from minimum makespan for each problem set

Number of activities	No of resources	Avg. Deviation from Min. Makespan (%)													
		MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
		S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
50	1	16.89	4.92	6.48	3.35	10.45	3.03	5.62	1.36	9.86	24.35	20.01	22.53	24.28	40.17
	5	1.90	27.82	27.89	23.98	30.84	24.99	28.69	22.28	29.83	4.73	3.79	5.01	4.65	37.52
	10	0.27	30.61	30.66	29.84	30.78	30.38	30.40	29.99	30.87	7.82	3.44	6.73	6.75	31.35
	15	0.66	32.31	32.24	32.01	32.31	32.31	32.30	31.99	32.31	8.66	3.50	7.11	7.69	32.31
Average		**4.93**	**23.92**	**24.32**	**22.30**	**26.10**	**22.68**	**24.25**	**21.41**	**25.72**	**11.39**	**7.69**	**10.35**	**10.84**	**35.34**
100	1	9.30	3.33	9.89	4.66	12.04	4.62	8.30	0.32	12.25	19.13	14.56	18.28	19.28	32.36
	5	4.97	18.16	22.38	19.08	23.54	20.30	21.12	17.38	23.67	2.89	5.39	11.61	2.86	25.56
	10	6.12	22.47	22.95	22.10	23.30	22.79	22.87	21.88	23.25	3.39	2.65	10.09	2.05	23.25
	15	5.56	21.64	21.62	21.01	21.77	21.77	21.59	21.24	21.77	3.05	1.90	9.94	3.10	21.77
Average		**6.49**	**16.40**	**19.21**	**16.71**	**20.16**	**17.37**	**18.47**	**15.21**	**20.24**	**7.12**	**6.13**	**12.48**	**6.82**	**25.74**
200	1	7.04	1.76	7.05	3.85	8.72	1.97	6.09	0.27	8.43	13.84	10.70	13.06	13.83	7.29
	5	2.59	16.63	19.56	17.17	20.15	17.03	18.92	15.11	19.98	2.71	3.63	7.72	2.01	20.59
	10	3.34	19.15	19.56	18.97	19.68	19.26	19.37	18.60	19.67	1.97	1.53	7.16	0.89	19.74
	15	3.97	18.94	18.99	18.65	19.00	18.95	18.94	18.70	19.00	2.56	2.03	7.22	2.15	19.00
Average		**4.24**	**14.12**	**16.29**	**14.66**	**16.89**	**14.30**	**15.83**	**13.17**	**16.77**	**5.27**	**4.47**	**8.79**	**4.72**	**16.66**
500	1	6.99	1.44	7.77	3.28	9.21	2.09	5.93	0.05	9.02	10.92	9.02	12.29	10.22	7.77
	5	2.00	15.00	18.00	16.00	19.00	16.00	18.00	14.00	19.00	2.00	3.00	6.00	1.00	16.00
	10	1.42	18.12	18.57	17.80	18.60	18.19	18.45	17.59	18.61	2.53	1.37	5.32	1.54	18.61
	15	1.40	16.93	16.97	16.26	16.98	16.93	16.87	16.31	16.98	2.49	0.65	5.21	1.63	16.98
Average		**2.95**	**12.87**	**15.33**	**13.34**	**15.95**	**13.30**	**14.81**	**11.99**	**15.90**	**4.49**	**3.51**	**7.21**	**3.60**	**14.84**
Total average		**4.63**	**16.85**	**18.82**	**16.75**	**19.77**	**16.91**	**18.33**	**15.47**	**19.64**	**7.08**	**5.43**	**9.72**	**6.51**	**23.14**

4.6 Resource Usage Profile Comparisons

In order to provide a visual representation of the differences in the results obtained by the various resource leveling approaches experienced in this thesis, resource histograms are plotted in Figures 4.1 to 4.5. For this purpose, a case problem named "E50 1-4-10" is chosen which consists of 50 activities, 1 resource types, with an OS of 0.7. In the following figures, the *x*-axis represents project workdays and *y*-axis displays resource utilization as man-hours per day. In Figure 4.1, the unleveled resource profile associated with resource-1 of the original early start CPM schedule is illustrated. Obviously, the overall duration of the project is rather short with 42 days in its current state; nevertheless, many undesired fluctuations in the resource utilization ranging from 128 to 672 man-hours per day can be noticed in the unleveled resource usage profile.

Figures 4.2, 4.3, 4.4, and 4.5 represent, respectively, the resource usage profiles for resource-1 of the same case problem leveled by MSP 2019, Primavera P6 with Late Finish-Descending priority, Asta PowerProject with Activity ID priority, and Serial Scheduling Scheme with Activity ID priority. The effect of resource leveling can easily be observed in any of the leveled resource profiles given. The fluctuations are significantly decreased for any of the leveling attempts with each satisfying the peak daily resource consumption of 80 man-hours per day compared to 672 man-hours per day in its unleveled state. Noticeably, this has been made possible by shifting forward and decreasing the overlapping segments of the parallel activities requiring the same type of resources – more than its availability – at the same time. In other terms, the constraints on the number of the available resources have been satisfied by increasing the overall makespan of the project. Therefore, the original CPM duration of 42 days is increased to a value beyond 200 days in any of the leveling attempts.

Furthermore, it was already highlighted in sections 4.4.1 to 4.4.3 that for problems with 50 activities and 1 resource type with an OS value of 0.7, the best solutions with the lowest average deviation is found by PowerProject when MP priority was used. This closure can be acknowledged when the outputs of the leveling processes are represented graphically in the ensuing figures. By looking at the profiles, one can easily see that MSP and P6 have performed relatively the same, with PowerProject

outperforming them all and SSS providing a histogram with the deepest troughs and the longest makespan which is undesirable. It can be seen that the shortest makespan of 211 is found by Primavera P6 with LF (Desc.) priority, PowerProject with ID priority and MSP tied with a makespan of 212 next to it. The duration found by SSS is 234 which is quite close but noticeably longer than those of the foregoing approaches. It can be argued that distinguishing the better performing tool would not be easy by only considering the resource profiles and short of objective function values. As pointed out before, in order for better evaluation of resource leveling capabilities of the methods for projects with limited resources, a more holistic approach is taken in this thesis as in addition to the makespan minimization abilities, leveling capabilities are also considered. Thus, the best performing approach – as described in section 4.5 – cannot be identified simply by taking a look at the overall durations of the leveled schedules. Rather, objective function values should also be considered to learn about the leveling capabilities of the different methods. More precisely, for the case example presented in Figures 4.2 to 4.5, all the three software packages have found solutions with virtually the same makespan of either 211 or 212 days; but when SSQR values are examined, PowerProject turns out to provide the best tool with the smallest objective function of 12,625 compared to 12,633, 12,625, and 22,405 values of, respectively, MSP, P6, and SSS. That is, among the three main software experimented, P6 while maintaining the shortest makespan is only able to provide a leveled schedule with the largest SSQR value.

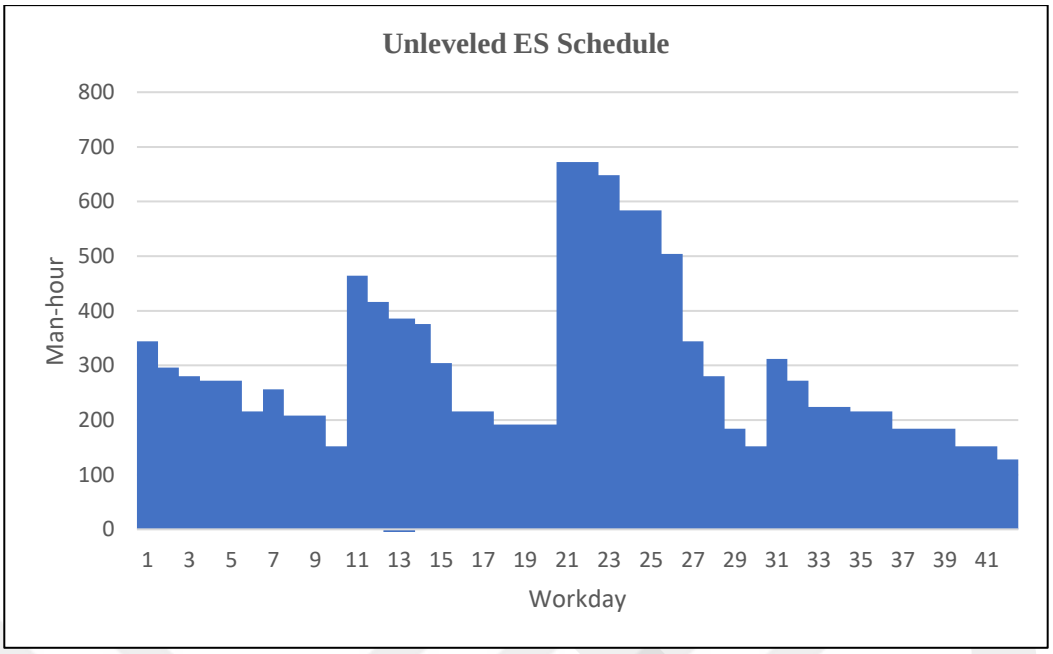

Figure 4.1 Unleveled resource usage profile for resource-1 for early start CPM schedule of 'E50 1-4-10' instance

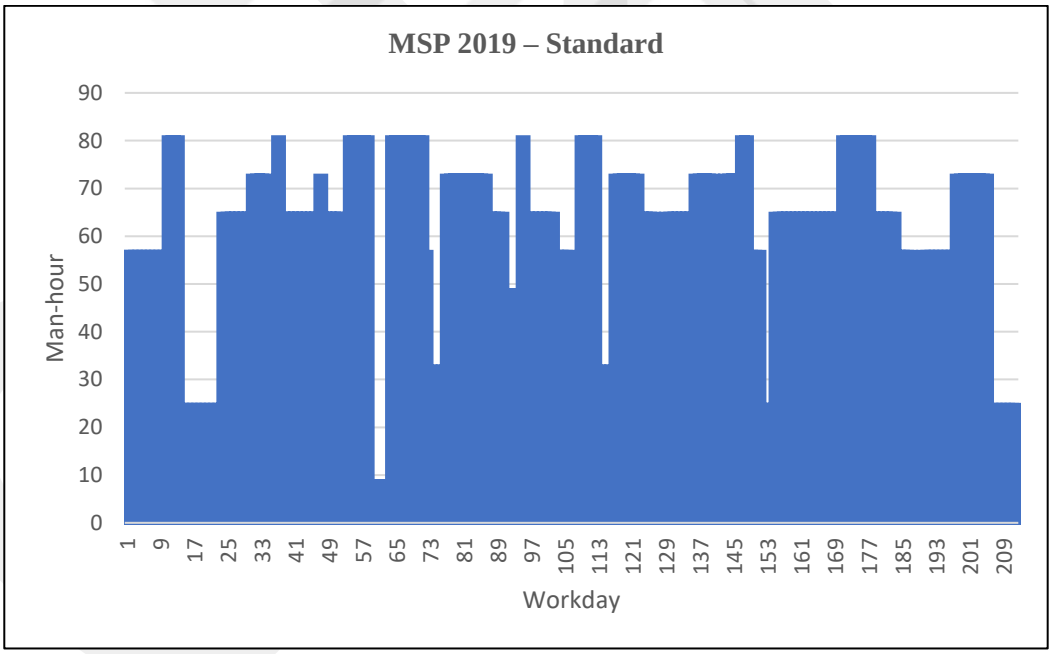

Figure 4.2 Resource usage profile for resource-1 leveled by MSP 2019 for 'E50 1-4-10' instance

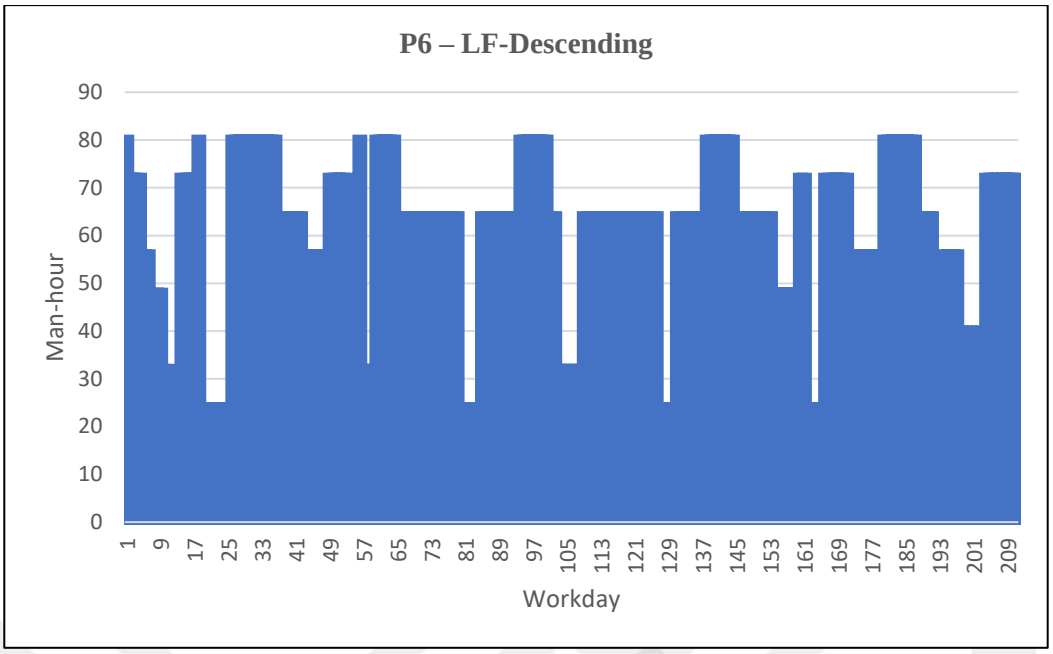

Figure 4.3 Resource usage profile for resource-1 leveled by Primavera P6 – LF (Desc.) for 'E50 1-4-10' instance

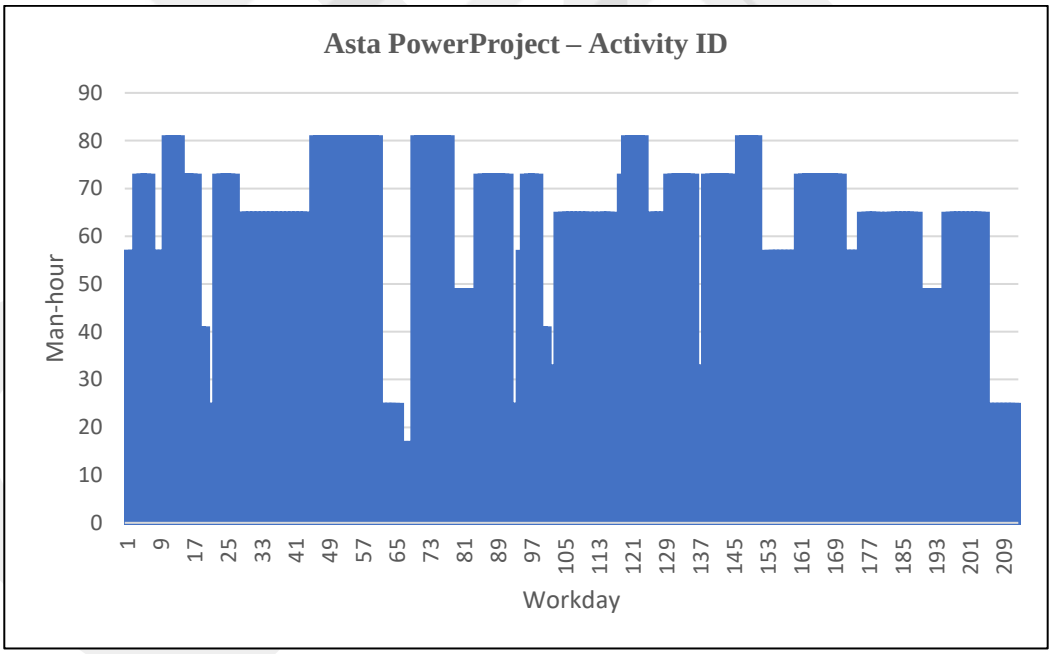

Figure 4.4 Resource usage profile for resource-1 leveled by Asta PowerProject – ID for 'E50 1-4-10' instance

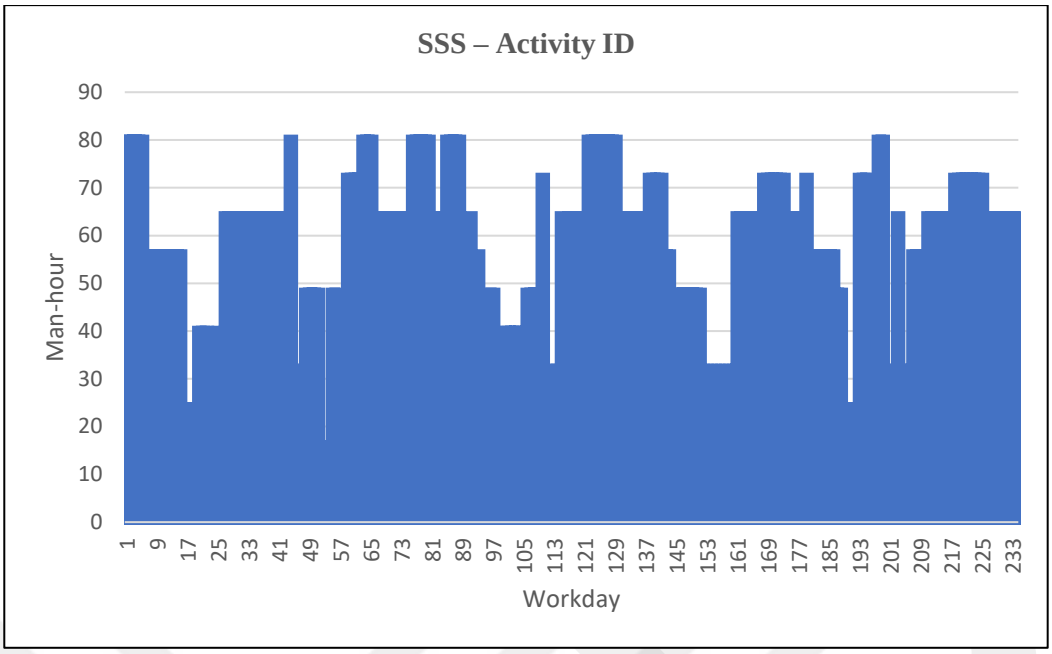

Figure 4.5 Resource usage profile for resource-1 leveled by Serial Scheduling Scheme – ID for 'E50 1-4-10' instance

4.7 Discussion of Results from Practical Perspective

In the light of the performance evaluations discussed earlier, some guidelines will be provided herein for the project managers for selection of the appropriate software packages for their real-life resource leveling needs. Selecting the suitable tool is crucial because real-life projects can include a diverse number of activities and resources which makes the leveling process quite complicated. Guidelines are provided based on two distinct criteria of effectiveness and efficiency for each of the project sizes (of 50, 100, 200, and 500 activities). Effectiveness of the approaches are evaluated first based on the leveling capabilities, then based on makespan minimization abilities.

- When leveling effectiveness, i.e., the objective function value is considered;

a. For problems with about 50 activities;

- For instances with a single resource type, Asta PowerProject 2019 with Total Float priority should be preferred;
- For instances with 5 resource types, Primavera P6 2019 with Total Float-Descending priority should be preferred;

- For instances with 10 resource types, Primavera P6 2019 with Late Finish-Descending priority should be preferred;
- For instances with 15 resource types, Primavera P6 2019 with any priority except Total Float-Ascending and Late Finish-Ascending should be preferred.

b. For problems with about 100 activities;

- For instances with a single resource type, Asta PowerProject 2019 with Total Float priority should be preferred;
- For instances with 5 resource types, Primavera P6 2019 with Late Finish-Descending priority should be preferred;
- For instances with 10 resource types, Primavera P6 2019 with Total Float-Descending priority should be preferred;
- For instances with 15 resource types, Asta PowerProject 2019 with Task Start Date priority should be preferred;

c. For problems with about 200 activities;

- For instances with a single resource type, Asta PowerProject 2019 with Total Float priority should be preferred;
- For instances with 5 resource types, Primavera P6 2019 with Total Float-Descending priority should be preferred;
- For instances with 10 resource types, Primavera 2019 with Late Finish-Descending should be preferred;
- For instances with 15 resource type, Primavera P6 with either Activity ID-Descending, Total Float-Descending, or Late Finish-Descending priorities should be preferred;

d. For problems with about 500 activities with any number of resource types Asta PowerProject 2019 with Task Start Date priority should be preferred.

A summary of the roadmap recommended for practitioners based on the leveling effectiveness of the leveling approach is demonstrated in Figure 4.6.

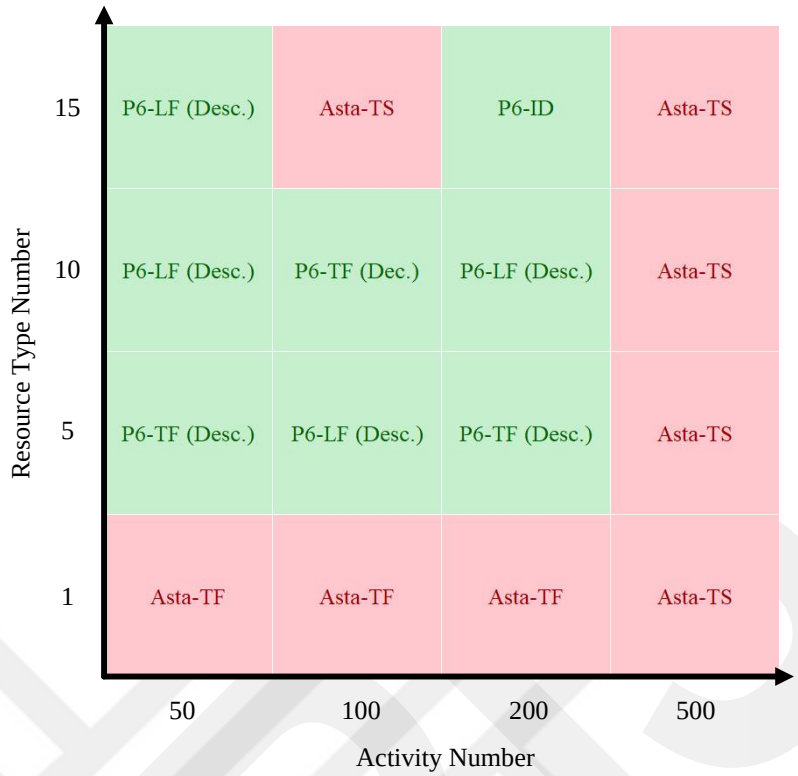

Figure 4.6 Guideline for selection of suitable leveling tool based on deviation from UB

- When makespan minimization effectiveness is considered;

a. For problems with about 50 activities;

- For instances with a single resource type, Primavera P6 2019 with Late Finish-Ascending priority should be preferred;
- For instances with 5 resource types, Microsoft Project 2019 should be preferred;
- For instances with 10 resource types, Microsoft Project 2019 should be preferred;
- For instances with 15 resource types, Microsoft Project 2019 should be preferred.

b. For problems with about 100 activities;

- For instances with a single resource type, Primavera P6 2019 with Late Finish-Ascending priority should be preferred;
- For instances with 5 resource types, Asta PowerProject 2019 with Multi Priority should be preferred;

- For instances with 10 resource types, Asta PowerProject 2019 with Multi Priority should be preferred;
- For instances with 15 resource types, Asta PowerProject 2019 with Activity ID Priority should be preferred.

c. For problems with about 200 activities;

- For instances with a single resource type, Primavera P6 2019 with Late Finish-Ascending priority should be preferred;
- For instances with 5 resource types, Asta PowerProject 2019 with Multi Priority should be preferred;
- For instances with 10 resource types, Asta PowerProject 2019 with Multi Priority should be preferred;
- For instances with 15 resource types, Asta PowerProject 2019 with Activity ID Priority should be preferred.

d. For problems with about 500 activities;

- For instances with a single resource type, Primavera P6 2019 with Late Finish-Ascending priority should be preferred;
- For instances with 5 resource types, Asta PowerProject 2019 with Multi Priority should be preferred;
- For instances with 10 resource types, Asta PowerProject 2019 with Activity ID should be preferred;
- For instances with 15 resource types, Asta PowerProject 2019 with Activity ID Priority should be preferred.

A summary of the instructions recommended for project managers based on the makespan minimization effectiveness of the leveling approach is demonstrated in Figure 4.7.

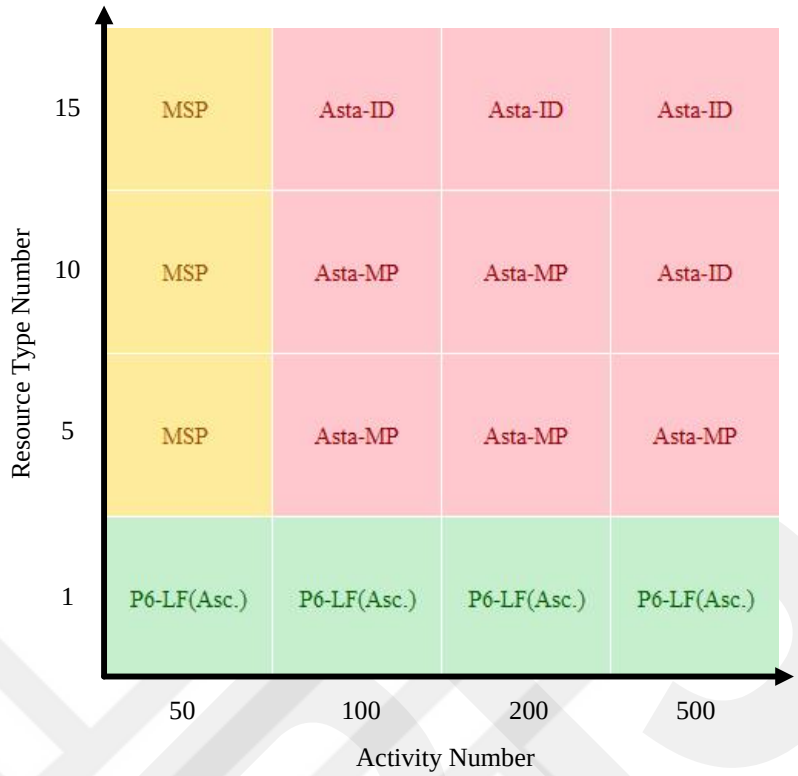

Figure 4.7 Guideline for selection of suitable leveling tool based on deviation from Minimum Makespan

- When efficiency, i.e., the leveling process computation time is considered;

a. For problems with about 50 activities with any number of resource types Primavera P6 2019 should be preferred;

b. For problems with about 100 activities with any number of resource types Primavera P6 2019 should be preferred;

c. For problems with about 200 activities with any number of resource types Primavera P6 2019 should be preferred;

d. For problems with about 500 activities with any number of resource types Primavera P6 2019 should be preferred.

CHAPTER 5

CONCLUSIONS

Despite significance of resource constrained project scheduling in real-life projects, studies focusing on leveling capabilities of the commonly practiced commercial software packages is relatively scant. The widespread use of such programs, in addition, the ease of access to their resource leveling modules further substantiates the importance of this subject matter. Eventually, this study has taken a significant step in filling this gap by using 640 examples that had been generated in a previous study. Instances adopted from the literature were originally configured to include a wide range of combination of different parameters; viz., activity number ranging from 50 to 500, resource type number varying between 1 and 15, and network complexity factor ranging from 0.1 to 0.7. Some minor adjustments were made to adapt the existing problems to leveling with resource availability considerations. The sample problems were fed into the latest versions – as per the date of this study – of three more widely used commercial project management software packages of Microsoft Project Professional 2019, Primavera P6 Professional 2019, and Asta Powerproject version 15.0.01.489. Comparative analyses were carried out over the foregoing software with the aim of experimenting their effectiveness and efficiency at leveling of the constrained project resources.

Throughout the analyses, 13 of the most common leveling priorities that are frequently implemented in the literature and are used in practice were exercised. Microsoft Project was experimented by using the standard priority, Primavera P6 with eight different priorities, and Asta PowerProject by selecting four distinct priority rules. Furthermore, a simple MATLAB code was prepared for implementation of a straightforward yet effective heuristic method known as Serial Scheduling Scheme and its results were compared to those achieved by the three software under scrutiny.

As a result, a total of 14 different method/priority combinations were experimented for each individual problem.

In order for better evaluation of resource leveling capabilities of the different methods over projects with limited resources, a more holistic approach was taken as in addition to makespan minimization capabilities, the leveling capabilities abilities were also studied. Leveling effectiveness of the leveling approaches were assessed based on Sum of Squares (SSQR) objective function values. Since optimal solutions were not available in the literature for any of the instances used, the percent deviations from the Upper Bounds (UB) were used instead. The UB values for each instance were decided by determining the smallest objective functions among the 14 values calculated. After setting the UB values, deviations from UB for every leveling attempt were measured in percentages. The same rationale was used to investigate the makespan minimization capabilities of the three main software. That is, the value for minimum makespan was decided by determining the shortest overall project duration among the 14 attempts. This value was used afterwards to calculate the deviation in percentages.

The findings of the leveling process reveal while all the three software packages manage to provide comparable results, Asta PowerProject – especially with Task Start Date and Multi Priority priorities – transpire to be the all-round best performing method. Nevertheless, especially for large problems that include high resource type numbers, Asta PowerProject and Microsoft Project were found not to be as efficient as Primavera P6. On the other hand, although the results found by Serial Scheduling Scheme were reasonably close to the corresponding UBs over the small-scale projects, the results were not so promising for the medium and large-scale instances; in that, the leveled resource usage profiles included undesirable deep troughs with longer makespans.

Subsequent to the comparative studies and with respect to the results obtained, some guidelines are provided for the project managers for selection of the appropriate software packages for their real-life resource leveling practices. The following recommendations are provided based on the two main criteria of leveling effectiveness and efficiency of the tools investigated:

- For small projects (~50 activities) with low resource type numbers (up to 5 resources), Primavera P6 2019 with Total Float-Descending priority should be preferred;
- For medium projects (~100 to ~200 activities) with small resource type numbers (up to 5 resources), Primavera P6 2019 with Late Finish-Descending priority should be preferred;
- For the large projects (~500 activities) with low resource type number (up to 5 resources), Asta PowerProject with Task Start Date priority should be preferred.
- For all the instances regardless of the number of activities, with large resource type numbers (more than 5 resources), Asta PowerProject with Task Start Date priority should be preferred.

The author acknowledges that the CPU times reported could have some degree of measurement error due to inevitable human error, for, adopting a stopwatch for process time measurement purposes. Nevertheless, since the same technique is used during all the attempts, the results are firmly comparable. Hence, if the critical parameter is the computation time of the leveling process, project planners are recommended to use Primavera P6 because of its unmatched promptness. Taking into account the time required to level the resources by the commercial software packages it is concluded that they, except for Primavera P6, fail to solve large-scale problems within reasonable computation times. Thus, integrating faster algorithms for solution of resource constrained leveling problems appear to be an area which needs further improvements.

On the other hand, transferring data among the software is experienced to be an arduous and cumbersome endeavor. The challenges and practical hurdles to utilization of the software for resource leveling purposes as well as some practical information as to how should the data be imported to the different software packages are provided in this study. Nonetheless, further improvement of cross-platform data importing/exporting capabilities of the software is imperative to smoothness and simplicity of the leveling features they accommodate. In the future studies, the total float metric can also be implemented as an evaluation criterion as it appears to contribute to the leveling capabilities of the algorithms by increasing the average total float amounts per each project activity. Last but not least, analyzing the resource

leveling performances of different software packages for projects with constrained resources with regard to resource idle days and maximum daily resource demand metric (RID-MRD) remains another area to be investigated.

REFERENCES

[1] ISO, "10006: Quality Management systems-Guidelines for quality management in projects," 2003.

[2] M. Abdel-Basset, M. Ali, and A. Atef, "Resource levelling problem in construction projects under neutrosophic environment." vol. 76, no. 2, pp. 964-988, 2020.

[3] J. E. Kelley Jr and M. R. Walker, "Critical-path planning and scheduling." in Papers presented at eastern joint IRE-AIEE-ACM computer conference, 1959, pp. 160-173.

[4] D. G. Malcolm, J. H. Roseboom, C. E. Clark, and W. Fazar, "Application of a technique for research and development program evaluation." vol. 7, no. 5, pp. 646-669, 1959.

[5] A. Kastor and K. Sirakoulis, "The effectiveness of resource levelling tools for resource constraint project scheduling problem." vol. 27, no. 5, pp. 493-500, 2009.

[6] P. De, E. Dunne, J. B. Ghosh, and C. E. Wells, "Complexity of the discrete time-cost trade off problem for project networks." vol. 45, no. 2, pp. 302-306, 1997.

[7] R. Kolisch and S. Hartmann, "Heuristic algorithms for the resource-constrained project scheduling problem: Classification and computational analysis." in Project scheduling: Springer, 1999, pp. 147-178.

[8] R. Kolisch and S. Hartmann, "Experimental investigation of heuristics for resource-constrained project scheduling: An update." vol. 174, no. 1, pp. 23-37, 2006.

[9] J. Blazewicz, J. K. Lenstra, and A. R. Kan, "Scheduling subject to resource constraints: classification and complexity." vol. 5, no. 1, pp. 11-24, 1983.

[10] J. L. Ponz-Tienda, A. Salcedo-Bernal, and E. Pellicer, "A parallel branch and bound algorithm for the resource leveling problem with minimal lags." vol. 32, no. 6, pp. 474-498, 2017.

[11] H. Li, N. Chan, T. Huang, H. Guo, W. Lu, and M. Skitmore, "Optimizing construction planning schedules by virtual prototyping enabled resource analysis." vol. 18, no. 7, pp. 912-918, 2009.

[12] J. L. Ponz-Tienda, V. Yepes, E. Pellicer, and J. Moreno-Flores, "The resource leveling problem with multiple resources using an adaptive genetic algorithm." vol. 29, pp. 161-172, 2013.

[13] P. M. Institute, A Guide to the Project Management Body of Knowledge (PMBOK Guide), 6th ed. Project Management Institute 2017.

[14] K. El-Rayes and D. H. Jun, "Optimizing resource leveling in construction projects." vol. 135, no. 11, pp. 1172-1180, 2009.

[15] R. Petrovic, "On optimization of resource leveling in project plans." in Project planning by network analysis: proceedings of the 2nd international congress, 1969, vol. 268, p. 273.

[16] A. T. Mason and C. L. Moodie, "A branch and bound algorithm for minimizing cost in project scheduling." vol. 18, no. 4-part-i, pp. B-158-B-173, 1971.

[17] S. M. Easa, "Resource leveling in construction by optimization." vol. 115, no. 2, pp. 302-316, 1989.

[18] S. Karshenas and D. Haber, "Economic optimization of construction project scheduling." vol. 8, no. 2, pp. 135-146, 1990.

[19] K. A. Shah, F. Farid, and J. W. Baugh, "Optimal resource leveling using integer-linear programming." in Computing in Civil and Building Engineering, ASCE, 1993, pp. 501-508:

[20] M. Bandelloni, M. Tucci, and R. Rinaldi, "Optimal resource leveling using non-serial dyanamic programming." vol. 78, no. 2, pp. 162-177, 1994.

[21] M. Younis, and B. Saad, "Optimal resource leveling of multi-resource projects." vol. 31, no. 1-2, pp. 1-4, 1996.

[22] K. G. Mattila and D. M. Abraham, "Resource leveling of linear schedules using integer linear programming." vol. 124, no. 3, pp. 232-244, 1998.

[23] K. Neumann and J. Zimmermann, "Procedures for resource leveling and net present value problems in project scheduling with general temporal and resource constraints." vol. 127, no. 2, pp. 425-443, 2000.

[24] J. Son, and K. G. Mattila, "Binary resource leveling model: Activity splitting allowed." vol. 130, no. 6, pp. 887-894, 2004.

[25] M. Ç. Mutlu, "A branch and bound algorithm for resource leveling problem." M.A. thesis, Middle east technical university, Turkey, 2010.

[26] T. Gather, J. Zimmermann, and J. Bartels, "Exact methods for the resource levelling problem." vol. 14, no. 6, pp. 557-569, 2011.

[27] R. Kolisch, C. Schwindt, and A. Sprecher, "Benchmark instances for project scheduling problems." in Project scheduling: Springer, 1999, pp. 197-212.

[28] J. Rieck, J. Zimmermann, and T. Gather, "Mixed-integer linear programming for resource leveling problems." vol. 221, no. 1, pp. 27-37, 2012.

[29] A. Burgess and J. B. Killebrew, "Variation in activity level on a cyclical arrow diagram." vol. 13, no. 2, pp. 76-83, 1962.

[30] R. B. Harris, "Packing method for resource leveling (PACK)." vol. 116, no. 2, pp. 331-350, 1990.

[31] J. Martinez and P. Ioannou, "Resource leveling based on the modified minimum moment heuristic." in Computing in civil and building engineering, ASCE, 1993, pp. 287-294.

[32] M. A. S. Hiyassat, "Modification of minimum moment approach in resource leveling." vol. 126, no. 4, pp. 278-284, 2000.

[33] R. B. Harris, "Precedence and Arrow Networking Techniques for Construction." Wiley, New York, 1978.

[34] M. A. S. Hiyassat, "Applying modified minimum moment method to multiple resource leveling." vol. 127, no. 3, pp. 192-198, 2001.

[35] S. E. Christodoulou, G. Ellinas, and A. Michaelidou-Kamenou, "Minimum moment method for resource leveling using entropy maximization." vol. 136, no. 5, pp. 518-527, 2010.

[36] D. Savin, S. Alkass, and P. Fazio, "Construction resource leveling using neural networks." vol. 23, no. 4, pp. 917-925, 1996.

[37] N. Kartam and T. Tongthong, "An artificial neural network for resource leveling problems." vol. 12, no. 3, pp. 273-287, 1998.

[38] W.T. Chan, D. K. Chua, and G. Kannan, "Construction resource scheduling with genetic algorithms." vol. 122, no. 2, pp. 125-132, 1996.

[39] T. Hegazy, "Optimization of resource allocation and leveling using genetic algorithms." vol. 125, no. 3, pp. 167-175, 1999.

[40] S.S. Leu, C.H. Yang, and J.C. Huang, "Resource leveling in construction by genetic algorithm-based optimization and its decision support system application." vol. 10, no. 1, pp. 27-41, 2000.

[41] D. X. Zheng, S. T. Ng, and M. M. Kumaraswamy, "GA-based multiobjective technique for multi-resource leveling." in Construction Research Congress: Wind of Change: Integration and Innovation, 2003, pp. 1-8.

[42] A. B. Senouci, N. N. Eldin, "Use of genetic algorithms in resource scheduling of construction projects." vol. 130, no. 6, pp. 869-877, 2004.

[43] S. H. H. Doulabi, A. Seifi, and S. Y. Shariat, "Efficient hybrid genetic algorithm for resource leveling via activity splitting." vol. 137, no. 2, pp. 137-146, 2011.

[44] J. Roca, E. Pugnaghi, and G. Libert, "Solving an extended resource leveling problem with multiobjective evolutionary algorithms." vol. 4, no. 4, pp. 289-300, 2008.

[45] D. Heon Jun, K. El-Rayes,"Multiobjective optimization of resource leveling and allocation during construction scheduling" vol. 137, no. 12, pp. 1080-1088, 2011.

[46] M. A. Iranagh and R. Sonmez, "A genetic algorithm for resource levelling of construction projects." vol. 1047, p. 1054, 2012.

[47] K. Neumann and J. Zimmermann, "Resource levelling for projects with schedule-dependent time windows." vol. 117, no. 3, pp. 591-605, 1999.

[48] A. Colorni, M. Dorigo, and V. Maniezzo, "Distributed optimization by ant colonies." in Proceedings of the first European conference on artificial life, 1991, vol. 142, pp. 134-142: Paris, France.

[49] Y. Xiong, Y. P. Kuang, and R. Es, "Ant colony optimization algorithm for resource leveling problem of construction project." vol. 1, pp. 212-226, 2006.

[50] J. Son, M. Skibniewski, "Multiheuristic approach for resource leveling problem in construction engineering: Hybrid approach." vol. 125, no. 1, pp. 23-31, 1999.

[51] J. q. Geng, L. p. Weng, S. h. Liu, "An improved ant colony optimization algorithm for nonlinear resource-leveling problems." vol. 61, no. 8, pp. 2300-2305, 2011.

[52] J.X. Qi, Q. Wang, and X.Z. Guo, "Improved particle swarm optimization for resource leveling problem." in IEEE International Conference on Machine Learning and Cybernetics, 2007, vol. 2, pp. 896-901.

[53] N. Pang, Y. Shi, and Y. You, "Resource leveling optimization of network schedule based on particle swarm optimization with constriction factor." in IEEE International Conference on Advanced Computer Theory and Engineering, 2008, pp. 652-656.

[54] Y. Guo, N. Li, and T. Ye, "Multiple resources leveling in multiple projects scheduling problem using particle swarm optimization." in IEEE Fifth International Conference on Natural Computation, 2009, vol. 3, pp. 260-264.

[55] H. Alsayegh and M. Hariga, "Hybrid meta-heuristic methods for the multi-resource leveling problem with activity splitting." vol. 27, pp. 89-98, 2012.

[56] R. V. Johnson, "Resource constrained scheduling capabilities of commercial project management software." Project Management Institute, 1992.

[57] C. Maroto and P. Tormos, "Project management: an evaluation of software quality." vol. 1, no. 2, pp. 209-221, 1994.

[58] C. Mellentien and N. Trautmann, "Resource allocation with project management software." vol. 23, no. 3, pp. 383-394, 2001.

[59] O. Hekimoglu, "Comparison of the resource allocation capabilities of project management software packages in resource constrained project scheduling problems." M.A. thesis, Middle east technical university, Turkey, 2007.

[60] K. Çekmece, "The resource allocation capabilities of commercial project management software packages for resource constrained project scheduling problem" M.A. thesis, Middle east technical university, Turkey, 2009.

[61] E. Rezvan Khah, "The Resource allocation capabilities of commercial construction project management software for the resource leveling problem." M.A. thesis, Middle east technical university, Turkey, 2014.

[62] E. Demeulemeester, M. Vanhoucke, and W. Herroelen, "RanGen: A random network generator for activity-on-the-node networks." vol. 6, no. 1, pp. 17-38, 2003.

[63] H. Yeniocak, "An efficient branch and bound algorithm for the resource leveling problem." M.A. thesis, Middle east technical university, Turkey, 2013.

[64] S. Deshmukh, A. Sagale, M. Bais, and E. Trends, "Study of Scheduling In Microsoft Project Software." no. 5, pp. 419-428, 2019.

[65] A. Mahure and A. Ranit, "Project Management using Primavera P6." pp. 241-244, 2018.

[66] N. Turbit, "Asta Powerproject: Project Management Software."

[67] J. E. Kelley, "The critical-path method: resource planning and scheduling." 1963.

[68] M. J. Liberatore, B. Pollack-Johnson, and C. A. Smith, "Project management in construction: Software use and research directions." vol. 127, no. 2, pp. 101-107, 2001.

APPENDICES

APPENDIX A

LEVELING PROCESS DURATIONS

Table A.1 Leveling process computation times for 50-activity instances

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E50 1-1-1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-1-10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-9	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-2-10	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-1	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-2	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-3	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-4	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-7	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-8	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	30
E50 1-3-9	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-3-10	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-4-1	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-4-2	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-4-3	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-4-4	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-4-5	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-4-6	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-4-7	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35
E50 1-4-8	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	35

Table A.1 Leveling process computation times for 50-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E50 1-4-9	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.6	1.6	1	1.6	35
E50 1-4-10	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.6	1.6	1	1.6	35
E50 5-1-1	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-2	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-3	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-4	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-5	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-6	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-7	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-8	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-9	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-1-10	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-1	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-2	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-3	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-4	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-5	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-6	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-7	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-8	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-9	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-2-10	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-3-1	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	55
E50 5-3-2	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-3-3	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-3-4	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-3-5	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-3-6	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-3-7	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-3-8	1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-3-9	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-3-10	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-4-1	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-4-2	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-4-3	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-4-4	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-4-5	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-4-6	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	60
E50 5-4-7	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	65
E50 5-4-8	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	65
E50 5-4-9	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	65
E50 5-4-10	1.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2	2	2	2	65
E50 10-1-1	2	1	1	1	1	1	1	1	1	5	5	4	5	70
E50 10-1-2	2	1	1	1	1	1	1	1	1	8	8	7	8	70
E50 10-1-3	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-1-4	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-1-5	2	1	1	1	1	1	1	1	1	12	11	10	11	70

Table A.1 Leveling process computation times for 50-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E50 10-1-6	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-1-7	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-1-8	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-1-9	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-1-10	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-2-1	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-2-2	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-2-3	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-2-4	2	1	1	1	1	1	1	1	1	12	11	10	11	70
E50 10-2-5	2	1	1	1	1	1	1	1	1	16	11	10	11	70
E50 10-2-6	2	1	1	1	1	1	1	1	1	16	15	13	15	70
E50 10-2-7	2	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-2-8	2	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-2-9	2	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-2-10	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-1	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-2	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-3	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-4	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-5	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-6	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-7	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-8	2.5	1	1	1	1	1	1	1	1	16	15	4	15	70
E50 10-3-9	2.5	1	1	1	1	1	1	1	1	22	15	19	15	75
E50 10-3-10	2.5	1	1	1	1	1	1	1	1	22	27	19	15	75
E50 10-4-1	2.5	1	1	1	1	1	1	1	1	22	27	19	20	75
E50 10-4-2	2.5	1	1	1	1	1	1	1	1	22	27	19	20	75
E50 10-4-3	2.5	1	1	1	1	1	1	1	1	22	27	19	20	75
E50 10-4-4	2.5	1	1	1	1	1	1	1	1	22	27	19	20	75
E50 10-4-5	2.5	1	1	1	1	1	1	1	1	22	27	19	20	75
E50 10-4-6	2.5	1	1	1	1	1	1	1	1	22	27	19	20	75
E50 10-4-7	2.5	1	1	1	1	1	1	1	1	22	27	19	20	75
E50 10-4-8	2.5	1	1	1	1	1	1	1	1	22	27	20	25	75
E50 10-4-9	2.5	1	1	1	1	1	1	1	1	22	27	20	25	75
E50 10-4-10	2.7	1	1	1	1	1	1	1	1	22	21	21	20	75
E50 15-1-1	4	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-2	4	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-3	4	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-4	4	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-5	4	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-6	4	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-7	4	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-8	4	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-9	5	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-1-10	5	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-2-1	5	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-2-2	5	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-2-3	5	1	1	1	1	1	1	1	1	30	30	25	30	72

Table A.1 Leveling process computation times for 50-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E50 15-2-4	5	1	1	1	1	1	1	1	1	30	30	25	30	72
E50 15-2-5	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-2-6	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-2-7	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-2-8	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-2-9	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-2-10	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-1	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-2	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-3	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-4	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-5	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-6	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-7	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-8	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-9	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-3-10	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-4-1	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-4-2	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-4-3	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-4-4	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-4-5	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-4-6	5	1	1	1	1	1	1	1	1	44	44	40	45	72
E50 15-4-7	5	1	1	1	1	1	1	1	1	50	50	45	55	72
E50 15-4-8	5	1	1	1	1	1	1	1	1	50	50	45	55	72
E50 15-4-9	5	1	1	1	1	1	1	1	1	50	50	45	55	72
E50 15-4-10	5	1	1	1	1	1	1	1	1	50	50	45	55	72

Table A.2 Leveling process computation times for 100-activity instances

Project Name	CPU Time (Sec.)												
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E100-1-1-1	1.8	1	1	1	1	1	1	1	1	1	1	0.9	1	80
E100-1-1-2	1.9	1	1	1	1	1	1	1	1	1	1	0.9	1	80
E100-1-1-3	1.9	1	1	1	1	1	1	1	1	1	1	0.9	1	80
E100-1-1-4	1.6	1	1	1	1	1	1	1	1	1	1	0.9	1	80
E100-1-1-5	1.9	1	1	1	1	1	1	1	1	1	1	0.9	1	80
E100-1-1-6	1.8	1	1	1	1	1	1	1	1	1	1	0.9	1	80
E100-1-1-7	1.6	1	1	1	1	1	1	1	1	1	1	0.9	1	80
E100-1-1-8	1.8	1	1	1	1	1	1	1	1	1	1	0.9	1	80
E100-1-1-9	1.4	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-1-10	1.8	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-1	1.7	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-2	1.7	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-3	1.8	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-4	1.8	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-5	1.6	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-6	1.6	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-7	1.4	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-8	1.5	1	1	1	1	1	1	1	1	1	1	1	1	80
E100-1-2-9	1.7	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-2-10	1.8	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-3-1	1.9	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-3-2	1.6	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-3-3	1.9	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-3-4	1.8	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-3-5	1.7	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-3-6	1.9	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-3-7	1.9	1	1	1	1	1	1	1	1	2	2	1	1	80
E100-1-3-8	1.9	1	1	1	1	1	1	1	1	2	2	2	1	80
E100-1-3-9	1.7	1	1	1	1	1	1	1	1	2	2	2	1	80
E100-1-3-10	1.8	1	1	1	1	1	1	1	1	2	2	2	3	80
E100-1-4-1	2	1	1	1	1	1	1	1	1	2	3	3	3	80
E100-1-4-2	2.1	1	1	1	1	1	1	1	1	2	3	3	3	80
E100-1-4-3	2.1	1	1	1	1	1	1	1	1	3	3	3	3	85
E100-1-4-4	2.3	1	1	1	1	1	1	1	1	3	3	3	3	85
E100-1-4-5	2.3	1	1	1	1	1	1	1	1	3	3	3	3	85
E100-1-4-6	2	1	1	1	1	1	1	1	1	3	3	3	3	85
E100-1-4-7	2.3	1	1	1	1	1	1	1	1	3	3	3	3	85
E100-1-4-8	2	1	1	1	1	1	1	1	1	4	3	3	3	85
E100-1-4-9	2	1	1	1	1	1	1	1	1	1	3	3	4	85
E100-1-4-10	2	1	1	1	1	1	1	1	1	1	3	3	4	85
E100-5-1-1	4	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-1-2	3	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-1-3	3	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-1-4	3	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-1-5	4	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-1-6	2.9	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-1-7	4	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-1-8	4.6	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-1-9	2.9	1	1	1	1	1	1	1	1	5	5	4	5	180

Table A.2 Leveling process computation times for 100-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E100-5-1-10	2.9	1	1	1	1	1	1	1	1	5	5	4	5	180
E100-5-2-1	4.8	1	1	1	1	1	1	1	1	11	11	10	12	180
E100-5-2-2	5	1	1	1	1	1	1	1	1	11	11	10	12	180
E100-5-2-3	4.8	1	1	1	1	1	1	1	1	11	11	10	12	180
E100-5-2-4	5	1	1	1	1	1	1	1	1	11	11	10	12	180
E100-5-2-5	4.4	1	1	1	1	1	1	1	1	11	11	10	12	180
E100-5-2-6	4.8	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-2-7	4.8	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-2-8	5	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-2-9	5	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-2-10	5	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-3-1	6.7	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-3-2	7	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-3-3	6.7	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-3-4	6.2	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-3-5	6.5	1	1	1	1	1	1	1	1	18	18	17	18	180
E100-5-3-6	6.5	1	1	1	1	1	1	1	1	18	18	17	18	190
E100-5-3-7	7	1	1	1	1	1	1	1	1	25	25	23	26	190
E100-5-3-8	6.2	1	1	1	1	1	1	1	1	25	25	23	26	190
E100-5-3-9	6.2	1	1	1	1	1	1	1	1	25	25	23	26	190
E100-5-3-10	6.7	1	1	1	1	1	1	1	1	25	25	23	26	190
E100-5-4-1	8	1	1	1	1	1	1	1	1	25	25	23	26	190
E100-5-4-2	9	1	1	1	1	1	1	1	1	25	25	23	26	190
E100-5-4-3	10	1	1	1	1	1	1	1	1	25	25	23	26	190
E100-5-4-4	10	1	1	1	1	1	1	1	1	25	25	23	27	190
E100-5-4-5	9.8	1	1	1	1	1	1	1	1	33	33	30	33	190
E100-5-4-6	9.5	1	1	1	1	1	1	1	1	33	33	30	34	190
E100-5-4-7	10	1	1	1	1	1	1	1	1	33	33	30	34	192
E100-5-4-8	10	1	1	1	1	1	1	1	1	33	33	30	34	192
E100-5-4-9	10	1	1	1	1	1	1	1	1	33	33	30	34	192
E100-5-4-10	11	1	1	1	1	1	1	1	1	33	33	30	34	192
E100-10-1-1	8	1	1	1	1	1	1	1	1	15	15	11	15	230
E100-10-1-2	6	1	1	1	1	1	1	1	1	15	15	11	15	230
E100-10-1-3	6.4	1	1	1	1	1	1	1	1	15	15	11	15	230
E100-10-1-4	6.5	1	1	1	1	1	1	1	1	15	15	11	15	230
E100-10-1-5	6	1	1	1	1	1	1	1	1	15	15	11	15	230
E100-10-1-6	8	1	1	1	1	1	1	1	1	20	20	17	15	230
E100-10-1-7	8	1	1	1	1	1	1	1	1	20	20	17	15	230
E100-10-1-8	9	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-1-9	6	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-1-10	9	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-1	9	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-2	10	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-3	9.5	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-4	9.4	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-5	9	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-6	9	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-7	9	1	1	1	1	1	1	1	1	20	20	17	20	230

Table A.2 Leveling process computation times for 100-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E100-10-2-8	11.37	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-9	8.8	1	1	1	1	1	1	1	1	20	20	17	20	230
E100-10-2-10	9	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-1	13.7	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-2	13.7	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-3	14	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-4	14	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-5	16	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-6	14	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-7	14	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-8	13.7	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-9	13.8	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-3-10	13.8	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-4-1	18	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-4-2	18	1	1	1	1	1	1	1	1	23	23	20	23	230
E100-10-4-3	18	1	1	1	1	1	1	1	1	28	28	25	29	240
E100-10-4-4	19	1	1	1	1	1	1	1	1	28	28	25	29	240
E100-10-4-5	19	1	1	1	1	1	1	1	1	28	28	25	29	240
E100-10-4-6	19	1	1	1	1	1	1	1	1	28	28	25	29	240
E100-10-4-7	19	1	1	1	1	1	1	1	1	28	28	25	29	240
E100-10-4-8	20	1	1	1	1	1	1	1	1	28	28	25	29	240
E100-10-4-9	20	1	1	1	1	1	1	1	1	28	28	25	29	240
E100-10-4-10	20	1	1	1	1	1	1	1	1	28	28	25	29	240
E100-15-1-1	15.5	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-2	15.5	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-3	10	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-4	9.3	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-5	9	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-6	9	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-7	8	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-8	9	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-9	14	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-1-10	9	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-2-1	12	1	1	1	1	1	1	1	1	25	25	22	25	247
E100-15-2-2	12	1	1	1	1	1	1	1	1	25	25	25	25	247
E100-15-2-3	12	1	1	1	1	1	1	1	1	25	25	25	25	247
E100-15-2-4	15	1	1	1	1	1	1	1	1	25	25	25	32	247
E100-15-2-5	15	1	1	1	1	1	1	1	1	25	25	25	32	247
E100-15-2-6	16	1	1	1	1	1	1	1	1	25	25	25	32	247
E100-15-2-7	16	1	1	1	1	1	1	1	1	33	33	25	32	247
E100-15-2-8	16	1	1	1	1	1	1	1	1	33	33	25	32	247
E100-15-2-9	17	1	1	1	1	1	1	1	1	33	33	25	32	247
E100-15-2-10	15	1	1	1	1	1	1	1	1	33	33	25	32	247
E100-15-3-1	16	1	1	1	1	1	1	1	1	33	33	25	34	247
E100-15-3-2	16	1	1	1	1	1	1	1	1	33	33	25	34	247
E100-15-3-3	16	1	1	1	1	1	1	1	1	33	33	25	34	247
E100-15-3-4	17	1	1	1	1	1	1	1	1	33	33	25	34	250
E100-15-3-5	20	1	1	1	1	1	1	1	1	33	33	25	34	250

Table A.2 Leveling process computation times for 100-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E100-15-3-6	20.8	1	1	1	1	1	1	1	1	33	33	25	34	250
E100-15-3-7	19.8	1	1	1	1	1	1	1	1	33	33	25	34	250
E100-15-3-8	24	1	1	1	1	1	1	1	1	33	33	28	34	250
E100-15-3-9	24	1	1	1	1	1	1	1	1	33	33	28	34	250
E100-15-3-10	26	1	1	1	1	1	1	1	1	33	33	28	35	250
E100-15-4-1	29.7	1	1	1	1	1	1	1	1	35	34	28	35	251
E100-15-4-2	31	1	1	1	1	1	1	1	1	35	34	30	35	251
E100-15-4-3	33	1	1	1	1	1	1	1	1	35	34	30	35	251
E100-15-4-4	31.8	1	1	1	1	1	1	1	1	35	34	30	35	251
E100-15-4-5	45.5	1	1	1	1	1	1	1	1	38	38	30	38	251
E100-15-4-6	40	1	1	1	1	1	1	1	1	38	38	30	38	251
E100-15-4-7	37.7	1	1	1	1	1	1	1	1	38	38	30	38	251
E100-15-4-8	31.7	1	1	1	1	1	1	1	1	38	38	30	38	251
E100-15-4-9	38.5	1	1	1	1	1	1	1	1	38	38	30	38	251
E100-15-4-10	29	1	1	1	1	1	1	1	1	38	38	30	38	251

Table A.3 Leveling process computation times for 200-activity instances

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E200-1-1-1	43	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-2	44	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-3	9.5	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-4	8.8	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-5	9	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-6	9	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-7	9	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-8	8.5	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-9	9	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-1-10	9	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-2-1	6.4	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-2-2	3.8	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-2-3	5.8	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-2-4	6.7	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-2-5	5.4	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-2-6	6.3	1	1	1	1	1	1	1	1	19	18	10	19	235
E200-1-2-7	5	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-2-8	5.9	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-2-9	5.9	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-2-10	6	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-1	6	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-2	6	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-3	5.5	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-4	6.7	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-5	5.7	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-6	5.7	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-7	6.7	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-8	5.7	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-9	6	1	1	1	1	1	1	1	1	19	18	10	19	243
E200-1-3-10	6.7	1	1	1	1	1	1	1	1	19	18	10	19	260
E200-1-4-1	8	1	1	1	1	1	1	1	1	20	20	10	19	260
E200-1-4-2	7.7	1	1	1	1	1	1	1	1	20	20	10	19	260
E200-1-4-3	7	1	1	1	1	1	1	1	1	20	20	10	20	260
E200-1-4-4	7	1	1	1	1	1	1	1	1	20	20	10	20	260
E200-1-4-5	8	1	1	1	1	1	1	1	1	20	20	10	20	260
E200-1-4-6	7.7	1	1	1	1	1	1	1	1	20	20	10	20	260
E200-1-4-7	7.7	1	1	1	1	1	1	1	1	20	20	10	20	260
E200-1-4-8	7.6	1	1	1	1	1	1	1	1	20	20	10	20	260
E200-1-4-9	7.3	1	1	1	1	1	1	1	1	20	20	10	20	260
E200-1-4-10	8	1	1	1	1	1	1	1	1	20	20	10	20	260
E200-5-1-1	17.6	1	1	1	1	1	1	1	1	25	25	10	22	435
E200-5-1-2	17.6	1	1	1	1	1	1	1	1	25	25	10	22	435
E200-5-1-3	17	1	1	1	1	1	1	1	1	25	25	10	22	435
E200-5-1-4	16.5	1	1	1	1	1	1	1	1	25	20	10	22	435
E200-5-1-5	13.7	1	1	1	1	1	1	1	1	25	20	10	22	435
E200-5-1-6	15	1	1	1	1	1	1	1	1	25	20	10	22	435
E200-5-1-7	16	1	1	1	1	1	1	1	1	25	20	10	22	435
E200-5-1-8	16	1	1	1	1	1	1	1	1	25	20	10	22	435
E200-5-1-9	15.7	1	1	1	1	1	1	1	1	25	25	10	22	435

Table A.3 Leveling process computation times for 200-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E200-5-1-10	16	1	1	1	1	1	1	1	1	50	50	30	50	435
E200-5-2-1	26	1	1	1	1	1	1	1	1	50	50	30	50	435
E200-5-2-2	27	1	1	1	1	1	1	1	1	53	52	33	52	435
E200-5-2-3	27	1	1	1	1	1	1	1	1	55	53	33	52	435
E200-5-2-4	28	1	1	1	1	1	1	1	1	55	53	33	52	435
E200-5-2-5	28	1	1	1	1	1	1	1	1	43	42	42	52	435
E200-5-2-6	25	1	1	1	1	1	1	1	1	52	52	32	52	435
E200-5-2-7	25	1	1	1	1	1	1	1	1	52	52	40	52	435
E200-5-2-8	25	1	1	1	1	1	1	1	1	52	52	33	52	435
E200-5-2-9	30	1	1	1	1	1	1	1	1	56	56	33	56	435
E200-5-2-10	30	1	1	1	1	1	1	1	1	56	56	32	56	435
E200-5-3-1	40	1	1	1	1	1	1	1	1	56	53	40	53	435
E200-5-3-2	36.5	1	1	1	1	1	1	1	1	54	57	45	54	435
E200-5-3-3	43	1	1	1	1	1	1	1	1	56	56	45	54	435
E200-5-3-4	42	1	1	1	1	1	1	1	1	56	56	45	54	435
E200-5-3-5	41	1	1	1	1	1	1	1	1	54	54	42	54	435
E200-5-3-6	45	1	1	1	1	1	1	1	1	54	54	42	54	435
E200-5-3-7	47	1	1	1	1	1	1	1	1	54	54	42	54	435
E200-5-3-8	47	1	1	1	1	1	1	1	1	56	56	45	59	450
E200-5-3-9	47	1	1	1	1	1	1	1	1	56	56	45	56	450
E200-5-3-10	46	1	1	1	1	1	1	1	1	56	56	45	59	450
E200-5-4-1	56	1	1	1	1	1	1	1	1	59	59	45	59	450
E200-5-4-2	56	1	1	1	1	1	1	1	1	59	59	45	59	450
E200-5-4-3	56	1	1	1	1	1	1	1	1	60	59	45	60	450
E200-5-4-4	56	1	1	1	1	1	1	1	1	60	60	48	60	450
E200-5-4-5	56	1	1	1	1	1	1	1	1	60	59	48	60	450
E200-5-4-6	57	1	1	1	1	1	1	1	1	62	60	48	60	450
E200-5-4-7	57	1	1	1	1	1	1	1	1	64	65	53	65	450
E200-5-4-8	56	1	1	1	1	1	1	1	1	62	62	53	62	450
E200-5-4-9	56	1	1	1	1	1	1	1	1	65	63	53	65	450
E200-5-4-10	56	1	1	1	1	1	1	1	1	65	62	53	65	450
E200-10-1-1	35	1	1	1	1	1	1	1	1	70	60	38	72	442
E200-10-1-2	31	1	1	1	1	1	1	1	1	70	60	38	72	442
E200-10-1-3	33	1	1	1	1	1	1	1	1	70	60	38	72	442
E200-10-1-4	30.3	1	1	1	1	1	1	1	1	70	60	40	72	442
E200-10-1-5	33	1	1	1	1	1	1	1	1	70	60	40	78	442
E200-10-1-6	33	1	1	1	1	1	1	1	1	70	65	40	78	442
E200-10-1-7	30.9	1	1	1	1	1	1	1	1	70	65	40	78	442
E200-10-1-8	30	1	1	1	1	1	1	1	1	79	65	45	78	442
E200-10-1-9	30	1	1	1	1	1	1	1	1	79	75	45	78	442
E200-10-1-10	35	1	1	1	1	1	1	1	1	79	75	45	78	442
E200-10-2-1	55	1	1	1	1	1	1	1	1	79	75	45	78	442
E200-10-2-2	55	1	1	1	1	1	1	1	1	79	75	45	78	442
E200-10-2-3	55	1	1	1	1	1	1	1	1	79	75	50	78	442
E200-10-2-4	55	1	1	1	1	1	1	1	1	79	75	50	78	442
E200-10-2-5	55	1	1	1	1	1	1	1	1	79	75	50	78	442
E200-10-2-6	53	1	1	1	1	1	1	1	1	79	75	50	78	442
E200-10-2-7	53	1	1	1	1	1	1	1	1	82	82	50	82	442

Table A.3 Leveling process computation times for 200-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E200-10-2-8	53	1	1	1	1	1	1	1	1	82	82	50	82	442
E200-10-2-9	53	1	1	1	1	1	1	1	1	100	98	80	82	442
E200-10-2-10	53	1	1	1	1	1	1	1	1	100	98	80	95	442
E200-10-3-1	90.3	1	1	1	1	1	1	1	1	100	98	80	95	442
E200-10-3-2	90.3	1	1	1	1	1	1	1	1	100	98	80	100	442
E200-10-3-3	95.8	1	1	1	1	1	1	1	1	100	98	80	100	442
E200-10-3-4	90.3	1	1	1	1	1	1	1	1	100	98	80	100	460
E200-10-3-5	90.3	1	1	1	1	1	1	1	1	100	98	80	100	460
E200-10-3-6	87	1	1	1	1	1	1	1	1	100	100	80	100	460
E200-10-3-7	94.4	1	1	1	1	1	1	1	1	102	100	85	100	460
E200-10-3-8	90.3	1	1	1	1	1	1	1	1	102	100	80	102	460
E200-10-3-9	92	1	1	1	1	1	1	1	1	102	102	80	102	460
E200-10-3-10	92	1	1	1	1	1	1	1	1	102	102	80	102	460
E200-10-4-1	120	1	1	1	1	1	1	1	1	150	150	109	150	460
E200-10-4-2	126	1	1	1	1	1	1	1	1	150	150	109	150	460
E200-10-4-3	123	1	1	1	1	1	1	1	1	150	150	110	150	460
E200-10-4-4	123	1	1	1	1	1	1	1	1	150	150	110	150	460
E200-10-4-5	138	1	1	1	1	1	1	1	1	150	150	110	150	460
E200-10-4-6	127	1	1	1	1	1	1	1	1	150	150	110	150	460
E200-10-4-7	143	1	1	1	1	1	1	1	1	150	150	110	150	460
E200-10-4-8	125	1	1	1	1	1	1	1	1	150	150	110	150	460
E200-10-4-9	119	1	1	1	1	1	1	1	1	160	150	110	160	460
E200-10-4-10	123	1	1	1	1	1	1	1	1	160	150	110	160	460
E200-15-1-1	53	1	1	1	1	1	1	1	1	180	147	81	190	481
E200-15-1-2	53	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-1-3	49	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-1-4	51	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-1-5	51	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-1-6	51	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-1-7	51	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-1-8	53	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-1-9	49	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-1-10	48	1	1	1	1	1	1	1	1	187	147	82	190	481
E200-15-2-1	88	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-2	98	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-3	98	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-4	103	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-5	98	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-6	92	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-7	98	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-8	92	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-9	103	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-2-10	103	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-3-1	120	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-3-2	125	1	1	1	1	1	1	1	1	200	192	137	200	481
E200-15-3-3	135	1	1	1	1	1	1	1	1	200	192	137	200	486
E200-15-3-4	135	1	1	1	1	1	1	1	1	200	192	137	200	486
E200-15-3-5	128	1	1	1	1	1	1	1	1	200	192	137	200	486

Table A.3 Leveling process computation times for 200-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E200-15-3-6	136	1	1	1	1	1	1	1	1	200	192	137	200	486
E200-15-3-7	140	1	1	1	1	1	1	1	1	226	192	137	228	486
E200-15-3-8	142	1	1	1	1	1	1	1	1	226	192	137	228	486
E200-15-3-9	149	1	1	1	1	1	1	1	1	226	192	137	228	486
E200-15-3-10	149	1	1	1	1	1	1	1	1	226	192	137	228	486
E200-15-4-1	190	1	1	1	1	1	1	1	1	226	192	137	228	486
E200-15-4-2	190	1	1	1	1	1	1	1	1	226	192	137	228	486
E200-15-4-3	193	1	1	1	1	1	1	1	1	226	192	137	228	486
E200-15-4-4	187	1	1	1	1	1	1	1	1	233	192	137	228	486
E200-15-4-5	195	1	1	1	1	1	1	1	1	233	230	137	228	486
E200-15-4-6	195	1	1	1	1	1	1	1	1	233	230	169	235	486
E200-15-4-7	195	1	1	1	1	1	1	1	1	233	230	169	235	486
E200-15-4-8	196	1	1	1	1	1	1	1	1	233	230	169	235	486
E200-15-4-9	198	1	1	1	1	1	1	1	1	233	230	169	235	486
E200-15-4-10	208	1	1	1	1	1	1	1	1	233	230	169	235	486

Table A.4 Leveling process computation times for 500-activity instances

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E500 1-1-1	45	1	1	1	1	1	1	1	1	35	37	16	36	1440
E500 1-1-2	45	1	1	1	1	1	1	1	1	35	37	16	36	1440
E500 1-1-3	45	1	1	1	1	1	1	1	1	38	37	16	36	1440
E500 1-1-4	45	1	1	1	1	1	1	1	1	35	25	13	36	1440
E500 1-1-5	45	1	1	1	1	1	1	1	1	38	40	15	35	1440
E500 1-1-6	45	1	1	1	1	1	1	1	1	32	37	12	35	1440
E500 1-1-7	50	1	1	1	1	1	1	1	1	35	37	12	36	1440
E500 1-1-8	50	1	1	1	1	1	1	1	1	38	37	16	36	1440
E500 1-1-9	50	1	1	1	1	1	1	1	1	37	36	16	36	1440
E500 1-1-10	50	1	1	1	1	1	1	1	1	37	36	16	36	1440
E500 1-2-1	50	1	1	1	1	1	1	1	1	37	36	16	36	1440
E500 1-2-2	50	1	1	1	1	1	1	1	1	37	36	16	36	1440
E500 1-2-3	50	1	1	1	1	1	1	1	1	37	36	16	36	1440
E500 1-2-4	50	1	1	1	1	1	1	1	1	37	36	25	36	1440
E500 1-2-5	50	1	1	1	1	1	1	1	1	37	36	25	36	1563
E500 1-2-6	50	1	1	1	1	1	1	1	1	56	56	30	53	1563
E500 1-2-7	50	1	1	1	1	1	1	1	1	56	56	30	53	1563
E500 1-2-8	50	1	1	1	1	1	1	1	1	56	56	30	53	1563
E500 1-2-9	50	1	1	1	1	1	1	1	1	56	56	30	53	1563
E500 1-2-10	50	1	1	1	1	1	1	1	1	60	56	30	53	1563
E500 1-3-1	55	1	1	1	1	1	1	1	1	60	56	30	53	1563
E500 1-3-2	55	1	1	1	1	1	1	1	1	65	70	35	56	1563
E500 1-3-3	55	1	1	1	1	1	1	1	1	65	70	35	56	1563
E500 1-3-4	65	1	1	1	1	1	1	1	1	65	70	35	56	1563
E500 1-3-5	65	1	1	1	1	1	1	1	1	65	65	35	65	1582
E500 1-3-6	65	1	1	1	1	1	1	1	1	65	65	35	65	1582
E500 1-3-7	65	1	1	1	1	1	1	1	1	65	65	35	65	1582
E500 1-3-8	65	1	1	1	1	1	1	1	1	65	65	35	65	1582
E500 1-3-9	65	1	1	1	1	1	1	1	1	65	65	35	65	1582
E500 1-3-10	65	1	1	1	1	1	1	1	1	65	69	40	65	1582
E500 1-4-1	70	1	1	1	1	1	1	1	1	65	69	40	65	1582
E500 1-4-2	70	1	1	1	1	1	1	1	1	65	69	40	65	1582
E500 1-4-3	70	1	1	1	1	1	1	1	1	65	69	40	65	1582
E500 1-4-4	70	1	1	1	1	1	1	1	1	65	69	40	65	1582
E500 1-4-5	70	1	1	1	1	1	1	1	1	70	69	40	65	1582
E500 1-4-6	70	1	1	1	1	1	1	1	1	70	69	40	65	1582
E500 1-4-7	75	1	1	1	1	1	1	1	1	70	70	40	65	1582
E500 1-4-8	78	1	1	1	1	1	1	1	1	70	70	40	65	1582
E500 1-4-9	78	1	1	1	1	1	1	1	1	70	70	40	65	1582
E500 1-4-10	78	1	1	1	1	1	1	1	1	70	70	40	65	1582
E500 5-1-1	170	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-1-2	170	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-1-3	170	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-1-4	170	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-1-5	170	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-1-6	170	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-1-7	170	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-1-8	170	1	1	1	1	1	1	1	1	350	345	280	348	2889

Table A.4 Leveling process computation times for 500-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E500 5-1-9	200	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-1-10	200	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-2-1	240	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-2-2	240	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-2-3	240	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-2-4	240	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-2-5	240	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-2-6	300	1	1	1	1	1	1	1	1	350	345	280	348	2889
E500 5-2-7	300	1	1	1	1	1	1	1	1	400	398	291	348	2889
E500 5-2-8	300	1	1	1	1	1	1	1	1	400	398	291	400	2889
E500 5-2-9	300	1	1	1	1	1	1	1	1	400	398	291	400	3060
E500 5-2-10	300	1	1	1	1	1	1	1	1	400	398	291	400	3060
E500 5-3-1	300	1	1	1	1	1	1	1	1	400	398	291	400	3060
E500 5-3-2	360	1	1	1	1	1	1	1	1	400	398	291	400	3060
E500 5-3-3	360	1	1	1	1	1	1	1	1	400	398	291	400	3060
E500 5-3-4	360	1	1	1	1	1	1	1	1	400	398	291	400	3060
E500 5-3-5	360	1	1	1	1	1	1	1	1	400	398	318	495	3060
E500 5-3-6	360	1	1	1	1	1	1	1	1	400	398	318	495	3060
E500 5-3-7	360	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-3-8	360	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-3-9	360	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-3-10	360	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-4-1	400	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-4-2	400	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-4-3	400	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-4-4	400	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-4-5	400	1	1	1	1	1	1	1	1	495	484	318	495	3060
E500 5-4-6	400	1	1	1	1	1	1	1	1	503	500	344	500	3060
E500 5-4-7	400	1	1	1	1	1	1	1	1	505	500	344	500	3060
E500 5-4-8	400	1	1	1	1	1	1	1	1	505	500	344	500	3060
E500 5-4-9	400	1	1	1	1	1	1	1	1	505	500	344	500	3060
E500 5-4-10	400	1	1	1	1	1	1	1	1	505	500	344	500	3060
E500 10-1-1	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-2	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-3	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-4	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-5	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-6	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-7	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-8	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-9	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-1-10	507	1	1	1	1	1	1	1	1	875	804	795	900	2803
E500 10-2-1	507	1	1	1	1	1	1	1	1	906	906	795	900	2803
E500 10-2-2	507	1	1	1	1	1	1	1	1	906	906	795	910	2803
E500 10-2-3	516	1	1	1	1	1	1	1	1	906	906	801	910	2803
E500 10-2-4	516	1	1	1	1	1	1	1	1	906	906	801	910	2803
E500 10-2-5	516	1	1	1	1	1	1	1	1	906	906	801	910	2803
E500 10-2-6	516	1	1	1	1	1	1	1	1	906	906	801	910	2803

Table A.4 Leveling process computation times for 500-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E500 10-2-7	516	1	1	1	1	1	1	1	1	906	906	801	910	2803
E500 10-2-8	516	1	1	1	1	1	1	1	1	959	906	801	910	2803
E500 10-2-9	516	1	1	1	1	1	1	1	1	959	906	801	910	2803
E500 10-2-10	516	1	1	1	1	1	1	1	1	959	906	801	910	2803
E500 10-3-1	529	1	1	1	1	1	1	1	1	959	906	801	910	2803
E500 10-3-2	529	1	1	1	1	1	1	1	1	959	906	801	910	2803
E500 10-3-3	529	1	1	1	1	1	1	1	1	959	923	801	910	2803
E500 10-3-4	529	1	1	1	1	1	1	1	1	959	923	801	910	2803
E500 10-3-5	529	1	1	1	1	1	1	1	1	959	923	801	910	2803
E500 10-3-6	529	1	1	1	1	1	1	1	1	959	923	801	910	2803
E500 10-3-7	529	1	1	1	1	1	1	1	1	959	923	801	910	2803
E500 10-3-8	529	1	1	1	1	1	1	1	1	959	923	801	910	2803
E500 10-3-9	529	1	1	1	1	1	1	1	1	959	923	801	910	2803
E500 10-3-10	529	1	1	1	1	1	1	1	1	959	923	801	910	2803
E500 10-4-1	540	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-2	540	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-3	540	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-4	540	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-5	540	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-6	540	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-7	545	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-8	545	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-9	545	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 10-4-10	545	1	1	1	1	1	1	1	1	1112	990	850	950	2805
E500 15-1-1	680	1	1	1	1	1	1	1	1	3600	3600	1380	3670	10890
E500 15-1-2	680	1	1	1	1	1	1	1	1	3600	3600	1380	3670	10890
E500 15-1-3	680	1	1	1	1	1	1	1	1	3600	3600	1380	3670	10890
E500 15-1-4	680	1	1	1	1	1	1	1	1	3600	3600	1380	3670	10890
E500 15-1-5	680	1	1	1	1	1	1	1	1	3600	3600	1380	3670	10890
E500 15-1-6	680	1	1	1	1	1	1	1	1	3600	3600	1380	3670	10890
E500 15-1-7	680	1	1	1	1	1	1	1	1	3600	3600	1380	3670	10890
E500 15-1-8	680	1	1	1	1	1	1	1	1	3600	3600	1380	3670	10890
E500 15-1-9	680	1	1	1	1	1	1	1	1	4830	4830	2056	5006	10890
E500 15-1-10	680	1	1	1	1	1	1	1	1	4830	4830	2056	5006	10890
E500 15-2-1	680	1	1	1	1	1	1	1	1	7200	4830	2056	7320	10890
E500 15-2-2	680	1	1	1	1	1	1	1	1	7200	4830	2056	7320	10890
E500 15-2-3	680	1	1	1	1	1	1	1	1	7200	4830	2056	7320	10890
E500 15-2-4	680	1	1	1	1	1	1	1	1	7200	4830	2056	7320	10890
E500 15-2-5	680	1	1	1	1	1	1	1	1	7200	4830	2056	7320	10890
E500 15-2-6	680	1	1	1	1	1	1	1	1	7200	4830	2056	7320	10890
E500 15-2-7	680	1	1	1	1	1	1	1	1	7200	4830	2056	7320	12670
E500 15-2-8	680	1	1	1	1	1	1	1	1	7200	6980	2056	7320	12670
E500 15-2-9	680	1	1	1	1	1	1	1	1	7200	6980	2056	7320	12670
E500 15-2-10	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	12670
E500 15-3-1	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	12670
E500 15-3-2	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	12670
E500 15-3-3	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	12670
E500 15-3-4	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	12670

Table A.4 Leveling process computation times for 500-activity instances (cont'd)

Project Name	CPU Time (Sec.)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E500 15-3-5	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	19830
E500 15-3-6	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	19830
E500 15-3-7	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	19830
E500 15-3-8	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	19830
E500 15-3-9	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	19830
E500 15-3-10	680	1	1	1	1	1	1	1	1	9540	9540	2578	9600	19830
E500 15-4-1	728	1	1	1	1	1	1	1	1	10680	10680	3600	10800	19830
E500 15-4-2	728	1	1	1	1	1	1	1	1	10680	10680	3600	10800	19830
E500 15-4-3	728	1	1	1	1	1	1	1	1	10680	10680	3600	10800	19830
E500 15-4-4	728	1	1	1	1	1	1	1	1	10680	10680	3600	10800	19830
E500 15-4-5	728	2	2	2	2	2	2	2	2	10680	10680	3600	10800	19830
E500 15-4-6	728	2	2	2	2	2	2	2	2	10680	10680	3600	10800	19830
E500 15-4-7	728	2	2	2	2	2	2	2	2	10680	10680	3600	10800	19830
E500 15-4-8	728	2	2	2	2	2	2	2	2	10680	10680	3600	10800	19830
E500 15-4-9	728	2	2	2	2	2	2	2	2	10680	10680	3600	10800	19830
E500 15-4-10	728	2	2	2	2	2	2	2	2	10680	10680	3600	10800	19830

APPENDIX B

SSQR OBJECTIVE FUNCTION VALUES

Table B.1 SSQR objective function values for 50-activity instances

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 1-1-1	168783	13091	13629	13745	13679	13047	13431	13571	13781	13339	11317	12173	11773	12241	18577	11317
E50 1-1-2	177126	14708	15544	15000	15862	15038	16130	15860	15492	15174	14666	14532	14422	14372	23294	14372
E50 1-1-3	242111	12659	13999	13665	13879	13167	14673	14195	13583	13631	12009	12383	12345	12147	18993	12009
E50 1-1-4	221182	13384	14362	14260	14518	13692	14238	14214	14528	13570	12676	13774	13326	13246	20718	12676
E50 1-1-5	97410	12008	12594	12424	13164	12300	12404	12596	13242	12330	11510	11646	11582	10840	19700	10840
E50 1-1-6	233303	15933	16727	16357	16409	16841	17011	16727	16577	16715	15367	15797	15911	15467	22721	15367
E50 1-1-7	119386	12904	14104	13558	13778	12688	13344	13656	13830	13332	12396	12120	11964	11964	21202	11964
E50 1-1-8	123349	10785	12079	12355	12039	12307	11833	11989	12305	11589	10785	11325	11011	10943	18795	10785
E50 1-1-9	145754	11388	11612	11776	12100	11792	12348	12116	12406	11928	10300	10586	11114	11114	18222	10300
E50 1-1-10	129360	13140	14252	14282	14598	13682	14042	14360	14422	13560	12944	13346	13288	12788	21154	12788
E50 1-2-1	128691	12733	13583	13949	14269	13153	13803	13569	13755	12931	12505	12659	11673	12345	18143	11673
E50 1-2-2	141591	13051	14431	14021	14359	14211	14779	14117	14919	14569	12847	13731	13653	13653	23395	12847
E50 1-2-3	111762	12300	12452	12680	12840	12158	12558	12450	12852	12140	12000	12240	12600	11674	18702	11674
E50 1-2-4	128073	13679	14865	14519	15265	14315	14859	15313	15053	14091	13285	13431	13349	13571	20731	13285
E50 1-2-5	114474	12336	13036	14252	14278	13830	12522	13666	14076	13776	11520	11595	11085	11743	20310	11085
E50 1-2-6	109433	13129	13391	13629	13645	12953	13839	13365	13833	13123	13033	12803	12669	12467	21347	12467
E50 1-2-7	124738	13940	15138	14074	15426	14698	14790	15714	15458	14518	13530	13306	13532	13972	22764	13306
E50 1-2-8	137853	13727	12079	12355	12039	12307	11833	11989	12305	11589	13865	14049	13685	13669	25517	11589
E50 1-2-9	113821	11027	11643	11449	11623	11343	11653	11549	11581	11673	10645	10637	10815	10907	16761	10637

Table B.1 SSQR objective function values for 50-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 1-2-10	125615	13579	14343	14379	14733	14251	14587	14617	14723	14221	13235	13607	13177	13297	21433	13177
E50 1-3-1	68866	9668	10648	10604	10584	10948	10606	10452	10922	10230	9064	9516	9418	9408	15038	9064
E50 1-3-2	92203	13497	14441	13969	13669	14185	15231	13953	14851	14143	12949	13649	13365	13095	23953	12949
E50 1-3-3	147073	14575	15273	14483	15151	14505	15389	15123	15771	14861	14305	14683	14369	14159	22963	14159
E50 1-3-4	83117	12545	12867	12961	13297	12575	13067	12835	13081	13043	12293	12743	12333	12471	19871	12293
E50 1-3-5	129856	14666	15912	15426	15670	15822	16336	15704	16740	15400	14634	15228	14502	14714	22454	14502
E50 1-3-6	96173	12479	13663	12789	13243	13013	13581	13339	13587	13339	12337	12895	12411	12389	18497	12337
E50 1-3-7	121391	14145	14715	14417	14713	13765	15219	15045	15381	14343	13501	14297	13639	13651	20509	13501
E50 1-3-8	112239	13425	13697	13859	13789	13993	14149	13685	14451	14107	12725	12643	13045	13365	19547	12643
E50 1-3-9	100319	11405	12347	12917	12697	11857	12463	11927	13047	12123	11127	11563	11323	10899	15311	10899
E50 1-3-10	86700	12666	13790	13854	14292	12878	13874	13628	14196	12736	12526	12386	12820	13296	18852	12386
E50 1-4-1	71694	11432	12308	12252	11718	11714	12370	12132	12602	11546	10986	11364	11156	11004	20554	10986
E50 1-4-2	79889	11175	12009	11839	12257	11575	12065	11359	12169	11559	10703	10737	10171	10809	14449	10171
E50 1-4-3	80022	12208	12714	13158	13412	11998	13638	12286	13480	12348	11804	12274	11836	11910	19282	11804
E50 1-4-4	59909	11051	11571	11771	11925	11339	11881	11737	11947	11141	10771	10671	10637	10559	21937	10559
E50 1-4-5	47747	10051	10247	9855	10221	10233	10331	10005	10849	10329	8661	9307	9045	8795	15291	8661
E50 1-4-6	77834	12642	12986	12274	13418	12808	13198	13538	13616	12904	12070	12274	12344	11922	19892	11922
E50 1-4-7	86070	12816	13614	12906	13558	12152	13844	12754	13596	12996	12168	12166	12562	12140	19290	12140
E50 1-4-8	83396	12666	13584	13174	13476	12884	13716	13316	13742	12832	12578	12784	12604	12478	18910	12478
E50 1-4-9	69268	11614	12394	12106	11928	12048	12612	12284	12224	11960	11486	11192	10884	11674	18592	10884
E50 1-4-10	72869	12633	12795	13427	13479	13071	13403	13131	13599	12663	12207	12625	12721	11849	22405	11849
E50 5-1-1	606290	54667	49041	48949	50053	47875	48939	49125	50601	49269	52705	53959	52313	52921	59115	47875
E50 5-1-2	479003	45929	40305	41011	41607	40929	41469	40903	41051	40403	45577	44793	44401	44685	50013	40305
E50 5-1-3	429953	51130	46478	45428	45848	44822	46810	46560	47178	45328	50118	50210	50616	50512	60082	44822
E50 5-1-4	621053	55517	48311	50013	49947	48161	49931	48421	49505	48161	54161	53523	54751	53931	65805	48161
E50 5-1-5	546399	53147	46207	46479	46921	45997	47159	45811	47713	46859	53055	52265	52259	50485	63205	45811
E50 5-1-6	365887	49803	44647	43397	44967	43595	43497	44021	45591	43069	48159	48641	47273	48163	56409	43069
E50 5-1-7	430243	50797	44659	44755	45397	42363	43693	45161	44773	42345	49081	47711	48089	48809	60033	42345
E50 5-1-8	720560	65340	58682	59830	60202	57962	59452	58682	60308	58856	63298	65774	63222	71116	74392	57962

Table B.1 SSQR objective function values for 50-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 5-1-9	439865	51256	45016	45350	45724	44694	44756	44292	45740	45540	48910	49470	48028	47912	54774	44292
E50 5-1-10	583265	51690	45892	45512	46282	45534	45866	45878	46286	46036	49788	51412	50400	50074	57572	45512
E50 5-2-1	466189	52015	46477	46871	45433	46515	46899	46203	47327	47099	50421	52213	50161	51999	56179	45433
E50 5-2-2	590927	61282	56512	55862	57228	55096	56032	56068	57794	55424	61028	62030	60158	61018	68178	55096
E50 5-2-3	542988	57826	51422	50298	51886	50834	51124	51904	52054	50518	55918	55558	55554	56262	70650	50298
E50 5-2-4	353511	51661	45863	44537	47409	44445	45461	46887	47541	44205	49651	51799	51069	51777	61461	44205
E50 5-2-5	559126	61050	51972	52798	54304	52060	52474	52496	53292	53108	60388	60082	57920	59818	74994	51972
E50 5-2-6	446483	49025	44329	43831	44263	44041	44091	43847	45431	44243	48949	50547	48931	48989	57531	43831
E50 5-2-7	444863	56525	50091	50983	50907	49531	50621	49953	50991	49631	55591	55235	56007	54333	61107	49531
E50 5-2-8	514085	56193	50111	49417	49891	49013	51079	49049	50075	49013	55475	57321	56431	56107	64309	49013
E50 5-2-9	389040	58278	52718	53666	53930	52306	52914	52896	53106	52660	57918	58040	57232	56838	63802	52306
E50 5-2-10	468488	59266	52774	53004	53582	52078	53000	52518	53584	52046	58106	57526	57010	57020	59708	52046
E50 5-3-1	403783	58203	52421	52527	52985	52317	52155	52139	53129	52211	57237	56913	57883	57383	76899	52139
E50 5-3-2	435980	61202	54674	53734	54174	54478	56418	54404	55346	55012	60566	60678	60488	59602	67704	53734
E50 5-3-3	397011	56986	48106	48636	49426	49744	51596	49584	49692	50528	55256	56954	55168	53874	60374	48106
E50 5-3-4	430685	61790	56598	53160	55508	52382	55608	53656	55958	52964	61698	60750	59832	60036	68530	52382
E50 5-3-5	322997	47825	42573	42485	42733	42307	43265	42537	43365	42527	47097	47801	47975	48573	59573	42307
E50 5-3-6	364132	53219	45459	46419	47433	46743	47009	45765	47257	46701	50903	52251	51743	51441	57575	45459
E50 5-3-7	424709	53101	47541	47771	48171	47055	47887	47287	48567	47285	51489	53431	52797	52319	59747	47055
E50 5-3-8	306961	53671	44933	45465	45683	46335	45617	45221	47059	46203	50805	53055	52017	51039	65097	44933
E50 5-3-9	534060	64185	56603	54935	55833	55271	57765	55799	56389	55103	61597	62465	61827	62243	68757	54935
E50 5-3-10	429496	65102	56644	54956	56472	54894	56764	56169	56140	55940	62792	62788	61860	62182	71870	54894
E50 5-4-1	397949	55054	48124	48610	48800	47308	48952	48698	48748	47350	55232	53844	54738	54554	61604	47308
E50 5-4-2	300499	47756	42912	42356	43576	42036	43508	43008	43170	41780	47514	47486	47044	47418	50702	41780
E50 5-4-3	324935	58429	51367	53109	53997	52493	53011	52281	53089	52533	57593	57437	57099	58533	72005	51367
E50 5-4-4	369960	60580	54714	52622	54632	53332	54236	53456	54134	53500	59918	60944	59458	60154	73872	52622
E50 5-4-5	348657	51469	43477	43101	43121	43457	44083	44555	45537	43653	48495	48359	49203	48185	54671	43101
E50 5-4-6	325773	56121	50139	49373	49817	49389	51023	51023	50915	49723	55999	56315	56449	56481	60727	49373
E50 5-4-7	352927	56455	49101	49033	48713	48519	49437	48593	50251	48519	54985	55583	57011	55531	60319	48519
E50 5-4-8	358242	56929	50095	50041	51369	50001	50035	50043	50361	50109	55201	56849	55853	56303	67435	50001

Table B.1 SSQR objective function values for 50-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 5-4-9	291037	50297	42889	42433	44403	42713	44095	42061	44675	41589	48115	48897	48037	49497	53317	41589
E50 5-4-10	286332	49865	43611	44935	44999	42047	43379	42831	45687	43539	48421	49757	49219	48229	60555	42047
E50 10-1-1	1856122	126424	108360	108724	108724	108064	108724	109076	108724	108724	124484	125286	123348	125004	111926	108064
E50 10-1-2	1656218	122162	95952	105958	105730	104106	104436	104436	104182	104436	119740	120614	117058	120664	107698	95952
E50 10-1-3	1440515	109285	90759	89847	91175	89847	90759	90759	93219	90759	100942	105773	102663	104081	93123	89847
E50 10-1-4	1298706	101418	87302	87950	88137	87721	87347	87302	87846	87619	89640	108096	95692	97344	87792	87302
E50 10-1-5	1497339	117863	96381	97221	99817	96243	97477	97711	99175	96381	107319	112795	108693	106456	109173	96243
E50 10-1-6	1631204	113408	93610	93610	93936	93610	93610	93610	93610	93610	102986	110011	104853	103610	96578	93610
E50 10-1-7	1508484	112136	95160	94780	93332	93118	93118	95160	93332	93118	101194	108660	105045	103031	94060	93118
E50 10-1-8	1043372	105474	93312	93312	93468	93312	93312	93312	93468	93312	102799	105069	103031	101939	93658	93312
E50 10-1-9	1254208	114260	100956	99052	101204	99052	99180	100956	99650	99180	107365	111871	107397	108236	101034	99052
E50 10-1-10	1400416	108736	92996	90160	92740	92996	92996	92996	92740	90416	100927	107088	103333	100571	95010	90160
E50 10-2-1	724396	104922	89176	89016	89176	89016	89016	89016	89176	89016	99503	101603	100039	99329	89194	89016
E50 10-2-2	818765	109231	91679	90143	90143	91031	91679	91943	90763	91055	101198	105825	102724	100577	100047	90143
E50 10-2-3	919705	97729	82507	82507	82507	82507	82507	82507	82507	82507	91891	94022	92383	91462	82781	82507
E50 10-2-4	1133200	110186	94668	94668	95074	94668	94668	94668	94668	94668	106464	109886	105546	105513	94668	94668
E50 10-2-5	883630	95270	83396	83396	83396	83396	83396	83396	83396	75935	93169	93704	92307	90858	84710	75935
E50 10-2-6	1203095	114019	97877	97937	98089	97725	97725	97877	97937	97725	107768	110447	109129	108780	98929	97725
E50 10-2-7	962169	113669	97439	97335	97565	97335	97439	97439	97439	97335	106035	109675	108973	107993	99321	97335
E50 10-2-8	973473	113177	97521	97521	98323	97521	97521	97521	97521	97521	106760	109708	106684	106832	103757	97521
E50 10-2-9	1068454	123518	107300	107300	107300	107300	107300	107300	109390	107300	117962	120965	120171	119357	107300	107300
E50 10-2-10	1021096	124584	106040	106040	110768	106040	106040	106040	108080	106040	117130	121952	119628	118704	106040	106040
E50 10-3-1	1072635	125692	108296	108620	108076	108076	108296	108076	108076	108076	120014	122956	125528	119080	110378	108076
E50 10-3-2	849943	117421	101543	102143	102941	102395	101543	101543	102397	101543	116716	117013	115593	115327	107737	101543
E50 10-3-3	777648	124708	108342	108342	108342	108342	108342	108342	108342	108342	122552	123814	122864	122762	108342	108342
E50 10-3-4	717677	112113	97535	97747	97929	97535	97747	97717	97535	97535	108711	108911	109679	109347	98007	97535
E50 10-3-5	680810	114358	97562	98858	98858	98480	97562	97562	98004	97562	111742	112862	111710	112648	104618	97562
E50 10-3-6	661523	102211	88045	88045	88045	88045	89025	88045	89025	88045	99371	100009	99793	99333	91089	88045
E50 10-3-7	725731	104639	89579	89451	89503	89451	89579	89579	89579	89451	102761	101647	101165	102661	105419	89451
E50 10-3-8	688188	103990	90440	91368	90440	90440	90440	90440	90440	90440	102930	103874	102070	103186	96016	90440

Table B.1 SSQR objective function values for 50-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 10-3-9	847641	115914	99300	99060	99300	99060	89406	99300	99300	99060	113106	113522	112898	112824	101472	89406
E50 10-3-10	1137846	124919	106111	108639	107247	106111	106111	106111	106111	106111	122049	122329	119779	121957	107275	106111
E50 10-4-1	819073	112855	96689	96689	96689	96689	97487	96689	97169	96689	111539	109311	111009	111263	98429	96689
E50 10-4-2	813693	116373	101187	101187	101187	101187	101187	101187	101187	101187	114541	114306	113278	110369	101187	101187
E50 10-4-3	723151	115717	99725	99725	99725	99725	99725	99725	102495	99725	111610	113256	112700	111665	99725	99725
E50 10-4-4	681581	115223	98875	98875	98875	98875	98875	98875	98875	98875	111060	112381	111237	112134	99161	98875
E50 10-4-5	666510	106406	88156	87856	88650	88702	89084	89002	88754	89078	100583	103411	102533	100636	97344	87856
E50 10-4-6	670747	113882	98468	98468	98468	98468	98468	98468	98468	98468	108029	111544	109846	109392	98468	98468
E50 10-4-7	679347	113215	98785	97969	98865	98785	98785	98785	98865	98785	108825	111272	110578	109799	101497	97969
E50 10-4-8	650288	107330	90830	91910	92282	90830	91202	90830	91910	90830	106261	104840	102495	104498	95906	90830
E50 10-4-9	690956	118026	103674	103674	103674	103674	103674	103674	103674	103674	115915	116860	116712	114636	103674	103674
E50 10-4-10	814335	126271	107567	106929	107567	107567	107567	107567	106787	107567	119890	122952	120261	121002	110167	106787
E50 15-1-1	1655231	169248	144610	144610	144610	144610	144610	144610	144610	144610	160637	165339	159449	157947	144610	144610
E50 15-1-2	1564177	153976	130336	130336	130336	130336	130336	130336	130336	130336	144829	150904	145725	146389	130336	130336
E50 15-1-3	1553815	163014	138170	138170	138170	138170	138170	138170	138170	138170	153013	157573	155808	151630	138170	138170
E50 15-1-4	1778718	162133	139137	139137	139137	139137	139137	139137	139137	139137	153121	159509	155505	153556	139137	139137
E50 15-1-5	2439420	167842	146782	146782	146782	146782	146782	146782	146782	146782	160204	166737	161038	159260	146782	146782
E50 15-1-6	1919864	188688	157228	157960	161976	157228	157228	157228	164074	157228	173610	183803	175459	172710	157228	157228
E50 15-1-7	1802360	177954	153868	153868	154498	153868	153868	153868	153868	153868	167887	175299	170075	167424	153868	153868
E50 15-1-8	2498850	180238	154446	154446	154446	154446	154446	154446	154446	154446	167258	177367	170822	166748	154446	154446
E50 15-1-9	1887578	176054	150430	150430	153370	150430	150430	150430	150430	150430	165034	170798	166912	164949	150430	150430
E50 15-1-10	1603219	153837	129389	129389	129389	129389	129389	129389	129389	129389	144318	147706	145826	144277	129389	129389
E50 15-2-1	1188746	157324	135152	135152	135152	135152	135152	135152	135152	135152	150530	156049	152818	152081	135152	135152
E50 15-2-2	1203187	171159	145601	143389	145601	145601	145601	145601	145601	145601	159929	166277	164253	162987	145601	143389
E50 15-2-3	1476374	166330	139534	139534	140522	139534	139534	139534	139534	139534	157636	163195	158242	160178	139534	139534
E50 15-2-4	1624721	196113	167237	167237	167237	167237	167237	167237	167237	167237	190034	193085	188749	186784	167237	167237
E50 15-2-5	1351381	161381	138733	138733	138733	138733	138733	138733	138733	138733	154341	160621	154619	157918	138733	138733
E50 15-2-6	1139492	139074	118948	118948	118948	118948	118948	118948	118948	118948	132431	137992	134507	131401	118948	118948
E50 15-2-7	1376310	175028	146382	146382	146382	146382	146382	146382	146382	146382	163922	173060	165369	165132	146382	146382
E50 15-2-8	1107373	167637	138313	138313	138313	138313	138313	138313	138313	138313	157673	161901	159497	156276	138313	138313

Table B.1 SSQR objective function values for 50-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 15-2-9	1597101	164855	138323	138323	138593	138323	138323	138593	138593	138323	156365	161395	158517	153619	138323	138323
E50 15-2-10	1406421	178279	149783	149783	149783	149783	149783	149783	149783	149783	166615	173185	169732	165427	149783	149783
E50 15-3-1	1014894	164600	144090	144618	144618	144090	144090	144090	144618	144090	160633	163637	159071	160176	144090	144090
E50 15-3-2	1079977	166679	142557	142557	142557	142557	142557	142557	142557	142557	158998	161075	162186	158452	142557	142557
E50 15-3-3	1143233	174705	146907	146907	146907	146907	146907	146907	146907	146907	169965	170841	170415	173053	146907	146907
E50 15-3-4	1113772	167650	144224	144224	144224	144224	144224	144224	144224	144224	162328	162938	162324	161944	144224	144224
E50 15-3-5	983484	162942	137130	137130	137130	137130	137130	137130	137130	137130	159608	160430	159350	158016	137130	137130
E50 15-3-6	1292484	146020	126174	126174	126174	126174	126174	126174	126174	126174	144912	145752	145408	144456	126174	126174
E50 15-3-7	1012658	158312	135172	135172	135926	135172	135172	135172	135172	135172	158172	156638	155250	158182	135172	135172
E50 15-3-8	1004046	152466	133494	133494	133494	133494	133494	133494	133494	133494	149936	151748	149386	151146	133494	133494
E50 15-3-9	1017034	151334	130926	130926	130926	130926	130926	130926	130926	130926	148870	150902	147620	147724	130926	130926
E50 15-3-10	1503032	200546	170892	171980	170892	170892	170892	170892	170892	170892	196968	197288	197862	196906	170892	170892
E50 15-4-1	2571596	169982	145718	145718	145718	145718	145718	145718	145718	145718	165586	169910	163748	165648	145718	145718
E50 15-4-2	1161521	181653	153573	153573	153573	153573	153573	153573	153573	153573	174485	176387	176307	174375	153573	153573
E50 15-4-3	1349039	160987	137063	137063	137063	137063	137063	137063	137063	137063	157347	158305	156603	158547	137063	137063
E50 15-4-4	892948	166076	141478	141478	141478	141478	141478	141478	141478	141478	164812	163110	163144	162964	141478	141478
E50 15-4-5	1041735	169371	143311	143311	143311	143311	143311	143311	143311	143311	164087	165533	163805	165533	143311	143311
E50 15-4-6	1881788	151760	130658	130658	130658	130658	130658	130658	130658	130658	143115	148350	145296	144881	130658	130658
E50 15-4-7	1332781	182177	159237	159237	159237	159237	159237	159237	159237	159237	176628	180071	177928	177200	159237	159237
E50 15-4-8	1128264	170684	148506	148506	148506	148506	148506	148506	148506	148506	164534	168867	164907	164797	148506	148506
E50 15-4-9	1520585	164959	141485	141485	141485	141485	141485	141485	141485	141485	157472	163414	160830	157134	141485	141485
E50 15-4-10	1199733	158775	135431	135431	135431	135431	135431	135431	135431	135431	151295	154614	150194	151712	135431	135431

Table B.2 SSQR objective function values for 100-activity instances

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-1-1-1	44011	22407	23243	20907	22707	20843	22373	21253	23187	20843	21414	21324	21801	21423	39491	20843
E100-1-1-2	33991	22539	22863	22359	22835	22305	22453	22649	23117	22185	22452	22507	22212	22487	29951	22185
E100-1-1-3	32110	23286	23486	22964	23610	22392	23214	23628	23658	22392	22678	22640	22106	22608	30030	22106
E100-1-1-4	49913	22551	22895	21637	22945	21335	22483	21861	23397	21335	21746	21975	21647	21758	31679	21335
E100-1-1-5	30045	22517	23027	22063	23003	21821	22473	22727	23269	21821	21929	22201	21212	21929	30473	21212
E100-1-1-6	41716	21696	22592	21332	22246	21392	21758	21938	22894	21392	22140	21952	21459	21482	36926	21332
E100-1-1-7	26306	20502	20680	19412	20730	19412	19412	20148	20876	19412	19232	19447	19035	19464	20272	19035
E100-1-1-8	34296	21978	21514	21444	21830	20980	21452	20758	22048	20980	20626	20811	20828	20637	26494	20626
E100-1-1-9	32090	23068	22866	22066	22532	21810	22534	22438	23058	21810	21983	22178	21578	21929	28186	21578
E100-1-1-10	34102	24436	24308	23744	24422	23446	24034	23930	24936	23446	23765	23907	23110	23615	27318	23110
E100-1-2-1	45178	24868	26186	25192	24852	24980	25816	24852	25660	24890	24135	25476	24808	24243	40138	24135
E100-1-2-2	44647	21959	22397	21761	21833	21677	22237	22455	22797	21645	21381	22080	21866	21549	36127	21381
E100-1-2-3	54368	26850	27072	25752	27112	25508	25882	26606	27724	25472	25407	25677	25363	25664	43782	25363
E100-1-2-4	59200	27134	28660	27346	28764	26806	27608	28486	28308	26806	25609	26319	26157	26066	46774	25609
E100-1-2-5	48895	23084	23014	22018	22446	21898	23218	23320	23254	21976	21759	22314	21606	21925	39948	21606
E100-1-2-6	57077	26065	27249	25863	27127	25745	26667	26949	27329	25745	25273	26547	25250	25479	45365	25250
E100-1-2-7	55431	24553	24261	23031	23621	25025	23643	23141	25093	23593	23226	23943	22411	23443	36125	22411
E100-1-2-8	38306	22352	22222	21816	21454	21920	22314	22122	22646	21454	21149	22059	21286	21198	35290	21149
E100-1-2-9	44586	23488	23688	22216	22082	24076	22602	22500	24336	22132	23055	23434	21505	22876	34500	21505
E100-1-2-10	40140	23316	23746	22886	23022	23464	23450	23182	24156	23018	22118	22448	22064	22011	38646	22011
E100-1-3-1	73378	23518	24760	24048	23798	24056	25402	24144	25130	23492	23013	23262	23212	23053	35198	23013
E100-1-3-2	81405	22085	23835	22573	22751	23149	24115	22745	24271	22537	21890	21390	20864	21269	35647	20864
E100-1-3-3	55306	22288	22391	22150	21829	22057	22731	21909	22867	21625	20636	21241	21666	20593	36866	20593
E100-1-3-4	73753	24801	24883	24231	23647	23815	25339	23491	25493	23663	23357	24001	23234	23285	39517	23234
E100-1-3-5	83024	24868	25958	24722	24860	24694	25036	25368	26506	24550	23567	23899	24463	23707	40516	23567

Table B.2 SSQR objective function values for 100-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-1-3-6	65065	22625	23761	22855	22509	24207	24097	23577	23623	22403	21204	22392	21701	21591	38343	21204
E100-1-3-7	87626	29142	30600	29432	28660	29714	30656	29118	31218	28954	28465	29702	29654	28258	48768	28258
E100-1-3-8	67848	25200	26516	24908	24734	25754	26028	24598	26712	24738	23811	24572	24020	24374	36394	23811
E100-1-3-9	63229	22065	23269	21805	21615	23021	22503	22969	23323	21541	20454	21427	20780	21493	34111	20454
E100-1-3-10	79481	23195	23881	22985	22049	23493	23465	22129	24117	21971	21540	21432	21904	20864	37205	20864
E100-1-4-1	154421	21527	22687	22001	22135	22105	22343	22381	23081	22257	20187	20988	20432	20201	36147	20187
E100-1-4-2	182304	23480	26174	25748	25006	25700	26220	25216	26578	24574	22101	23180	22771	23287	38848	22101
E100-1-4-3	199985	25319	26867	26263	26707	26559	27135	25721	27923	25961	24362	25417	24620	24361	45335	24361
E100-1-4-4	178556	23428	24954	24460	23468	24606	25030	24158	25042	23568	22093	22804	22492	21802	38714	21802
E100-1-4-5	148842	22206	24100	23680	23466	23992	24480	22878	24462	23240	21397	20948	21341	21347	36966	20948
E100-1-4-6	153817	22937	25383	24871	24121	24355	25737	25307	26043	24419	22033	23089	22413	21833	36257	21833
E100-1-4-7	191182	23588	26166	25890	25494	26190	26384	25632	26016	24862	22470	24076	23643	22167	36948	22167
E100-1-4-8	189340	24106	26036	26260	25202	27594	26804	26342	27602	25380	24258	24174	23511	23854	36484	23511
E100-1-4-9	136705	22429	23995	22815	23191	23511	24609	22875	24481	22917	21475	22003	22047	21109	36471	21109
E100-1-4-10	110600	18810	21072	20336	20278	20662	21154	20014	21660	20276	18392	19204	18467	18020	31866	18020
E100-5-1-1	194788	106590	100004	98508	99382	98508	98458	99702	100136	98508	96499	93872	80585	98732	137790	80585
E100-5-1-2	143743	86988	81956	81956	81956	81956	81956	81956	81956	81956	85745	85745	85267	85711	118645	81956
E100-5-1-3	119091	85264	81934	80318	81044	80258	80486	80492	81896	80258	85290	84251	83006	85273	107561	80258
E100-5-1-4	175861	107164	106496	101016	106032	101016	101316	102280	104060	101016	108492	106263	103761	108568	136661	101016
E100-5-1-5	167460	97438	92350	90818	93334	89970	89904	91966	95198	89970	97757	93618	87279	98371	133833	87279
E100-5-1-6	148595	99785	96243	95451	97095	95195	95433	96035	97835	95195	101537	101455	99407	101585	140931	95195
E100-5-1-7	182599	102152	96334	95604	98212	95604	96138	97446	98270	95604	101996	100946	86524	99071	125967	86524
E100-5-1-8	176173	108906	105800	102750	106010	102580	103152	104780	107142	102580	101526	104275	86540	103723	136513	86540
E100-5-1-9	134007	95115	91687	91741	91355	91741	91273	91777	91403	91741	96483	96891	94579	98466	124339	91273
E100-5-1-10	144647	99225	94131	93007	93853	92951	94243	93361	94131	93007	97311	97665	96761	98821	130577	92951
E100-5-2-1	185501	100599	91355	90361	91787	90361	90991	90619	91205	90361	100719	99345	97251	100899	121079	90361
E100-5-2-2	203429	106643	96485	94123	96759	94123	95181	95709	96727	94123	103809	104667	101869	105182	141729	94123
E100-5-2-3	188186	110133	100827	99679	100251	98983	98983	99651	100595	98983	110859	109149	105281	109752	125652	98983
E100-5-2-4	217811	109603	101261	99527	100193	99195	99275	100909	100587	99195	110154	107612	105913	110179	141415	99195
E100-5-2-5	198981	104131	95809	93231	95129	92979	93671	95529	95353	92979	102781	100398	99556	101210	127569	92979

Table B.2 SSQR objective function values for 100-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-5-2-6	236406	112918	104904	103862	106928	103862	104090	104930	104924	103862	113042	111230	109537	111059	138472	103862
E100-5-2-7	205658	110702	103638	101980	101276	102256	101974	102668	102928	102256	110698	109561	107742	111801	137490	101276
E100-5-2-8	220454	108191	98695	95651	96991	95633	95865	96697	97589	95633	105551	105506	103329	108231	134366	95633
E100-5-2-9	212584	118279	109091	108489	109115	108321	108745	108489	109523	108489	117153	118091	114458	118551	141794	108321
E100-5-2-10	217356	105872	100232	98402	99786	98318	99976	99024	99962	98318	105913	105103	104075	107514	125032	98318
E100-5-3-1	284945	104248	91886	90000	89386	89278	91152	89144	92744	89040	98457	101560	99001	100364	114379	89040
E100-5-3-2	388816	117614	108026	107408	108196	106230	106498	109928	106752	105642	113277	114566	113715	113819	143314	105642
E100-5-3-3	284593	108780	96962	94978	96218	96496	96600	96116	96406	96292	105571	104067	103575	104680	138455	94978
E100-5-3-4	242704	93605	83447	82061	84905	82039	84201	86613	83491	82039	92354	90749	89620	90770	112566	82039
E100-5-3-5	272818	103957	94803	92495	94473	92027	94157	92887	95303	92027	102462	101520	100702	102793	130780	92027
E100-5-3-6	283920	107810	95012	93134	94672	96008	95168	94660	94690	94550	102471	102502	103759	102925	125508	93134
E100-5-3-7	316684	110804	97040	98340	98700	96980	98910	97084	99168	97336	108099	108772	108789	108418	137372	96980
E100-5-3-8	277214	106154	93504	93508	94540	92192	93612	92642	95848	92144	103589	103010	101334	103458	123764	92144
E100-5-3-9	249360	108322	98582	96660	98370	96180	97394	96556	98902	95776	108256	107401	105105	107986	134342	95776
E100-5-3-10	283732	105016	91890	90748	90124	89182	91032	88346	93044	88906	100380	101899	99275	101200	124736	88346
E100-5-4-1	630484	93426	83124	82970	83582	81342	84104	82416	83064	82478	90292	92926	91114	89881	109472	81342
E100-5-4-2	671472	98955	88767	88801	90965	87717	89721	87681	88619	88231	94655	97786	99096	99193	127766	87681
E100-5-4-3	795720	111446	100488	99294	99728	96956	99648	98050	99782	97304	108902	109120	106812	107668	135214	96956
E100-5-4-4	685063	108626	96722	96908	97378	96224	97868	96470	97546	96200	108636	108826	108580	107958	128147	96200
E100-5-4-5	780840	118250	105208	105772	105116	104326	105844	105564	107734	103958	115914	114696	114736	115006	155820	103958
E100-5-4-6	604137	95991	83317	83581	83599	81683	83913	83819	86059	83021	92301	92867	92139	93571	110645	81683
E100-5-4-7	694736	113232	99236	100944	99500	99072	101032	98094	104428	98060	108782	110388	110034	109330	143144	98060
E100-5-4-8	710416	108508	95338	94166	96612	93276	94860	92866	96652	94072	106136	104678	104792	106516	147790	92866
E100-5-4-9	982433	124240	112152	108990	110532	110876	111460	109156	112766	108802	118638	122178	121972	123716	135865	108802
E100-5-4-10	896109	111581	101835	100097	101989	98747	102243	100979	102379	98213	111093	110289	110485	109971	142453	98213
E100-10-1-1	355317	203099	190005	186173	192151	184213	184981	184375	191367	184213	196844	195571	193179	198173	215949	184213
E100-10-1-2	315878	206561	196633	193817	196209	193817	193817	193817	196209	193817	205236	203938	199999	205735	197648	193817
E100-10-1-3	339578	225049	212063	212767	212767	212063	212063	212063	212767	212063	223457	222917	171781	223792	216466	171781
E100-10-1-4	350996	204916	190764	190764	190764	190764	190764	190764	190764	190764	204640	207264	199414	207542	199688	190764
E100-10-1-5	296587	203612	194878	189004	203288	189004	189474	189642	199356	189004	209183	207141	200691	208951	211329	189004

Table B.2 SSQR objective function values for 100-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-10-1-6	349765	196399	186007	181537	188917	181537	181537	183987	188399	181537	197715	196093	193563	197727	201125	181537
E100-10-1-7	347291	205325	191551	191551	198899	191551	191551	194913	192571	191551	199598	199698	198622	198622	187327	187327
E100-10-1-8	305987	200766	189602	188546	188546	189602	189602	189602	188546	189602	197701	192933	193256	194630	198225	188546
E100-10-1-9	270893	182786	168992	168482	171588	168482	169492	169422	171588	168482	185539	182819	180785	183121	187149	168482
E100-10-1-10	356426	212484	194476	196690	202126	194224	194224	194224	202042	194224	209312	205676	203250	209874	223014	194224
E100-10-2-1	362401	199817	181229	181469	181853	180845	180845	181229	181853	180845	194475	195475	198065	197065	192523	180845
E100-10-2-2	377559	196908	179850	179412	179412	179412	179412	179412	179850	179412	196629	194724	190496	197132	189845	179412
E100-10-2-3	427627	210911	196141	195997	197415	195997	195997	196141	197415	195997	215638	212402	204815	215023	198621	195997
E100-10-2-4	445439	209407	189889	189889	191605	189889	189889	189889	189889	189889	202099	201404	202099	203260	199183	189889
E100-10-2-5	383117	205212	187614	187614	187614	187614	187614	187614	187614	187614	193993	198543	193199	200931	190941	187614
E100-10-2-6	458167	238854	216938	216594	216686	216594	216846	216938	216938	216594	241408	242356	235982	244538	234855	216594
E100-10-2-7	368685	195290	178368	178368	178368	178368	178368	178368	178368	178368	196821	196696	196821	198139	191331	178368
E100-10-2-8	464074	225164	202000	202000	203476	202000	202000	202000	203476	202000	219499	216113	213467	221147	207704	202000
E100-10-2-9	390728	212738	192224	192224	192224	192224	192224	192392	192224	192224	213710	214349	210711	215723	196962	192224
E100-10-2-10	365256	197304	181276	179248	181438	179248	179248	181276	181438	179248	198691	199435	193330	199669	180710	179248
E100-10-3-1	621392	211246	186304	185934	185934	185934	185934	185934	187496	185934	211264	212983	206096	213319	201578	185934
E100-10-3-2	636741	211087	184467	184323	186303	184323	184323	184323	185403	184323	204359	204272	200976	204928	195775	184323
E100-10-3-3	629255	184037	166249	166249	166249	166249	166249	166249	166249	166249	181570	186436	180331	186670	172002	166249
E100-10-3-4	627225	191447	169219	168779	168779	168779	169219	168779	170349	168779	190909	190822	199949	191337	178631	168779
E100-10-3-5	707941	216004	187034	186708	193558	186570	186914	186570	187034	186570	215628	216108	213806	216864	188911	186570
E100-10-3-6	496100	200502	174654	174654	174654	174654	174654	174654	174654	174654	190529	193365	185823	188665	181540	174654
E100-10-3-7	560402	200651	172785	173349	172785	172785	173349	172785	172785	172785	198919	199045	195495	200521	184204	172785
E100-10-3-8	618498	224544	200438	200246	200246	200246	200438	200246	200438	200246	216495	220179	213252	219293	208226	200246
E100-10-3-9	635341	210931	189225	189225	189225	189225	189225	189225	189225	189225	211762	214057	209258	211914	202781	189225
E100-10-3-10	675637	204075	182559	182275	184811	182275	182275	182275	182275	182275	202888	206044	201472	204152	184997	182275
E100-10-4-1	1225320	186989	158683	159107	158135	157647	159107	159343	159107	157647	177887	183057	178499	176884	166990	157647
E100-10-4-2	1102188	218902	190428	190248	190248	190248	190248	190248	190428	190248	205029	204401	204331	204640	189274	189274
E100-10-4-3	1349996	215863	181205	182507	182349	181205	181205	181895	181889	181205	212568	217741	217262	215745	204818	181205
E100-10-4-4	1309584	211307	182931	182085	182085	180867	180783	180867	182931	180867	207152	208426	207192	207892	206758	180783
E100-10-4-5	1619583	215528	186952	187146	186952	186952	186952	186952	186952	186952	207727	209453	206653	207371	185739	185739

Table B.2 SSQR objective function values for 100-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-10-4-6	1349570	212038	182316	181974	182178	182316	182586	182096	182994	182210	211709	211879	210019	212023	187400	181974
E100-10-4-7	2011405	239984	209328	208440	208440	208440	209328	208440	209328	208440	224725	225999	219497	224980	217055	208440
E100-10-4-8	1377451	228033	196257	192063	193663	192063	195569	192993	196257	193003	216887	223474	220396	218930	204417	192063
E100-10-4-9	1470435	194628	165188	163788	163428	163788	165548	165188	165188	163788	180577	182127	180577	178820	168723	163428
E100-10-4-10	1545292	220107	191657	191657	191657	191657	191657	191657	191657	191657	215511	218895	216358	213677	190590	190590
E100-15-1-1	547810	299793	275351	274913	287061	274913	274913	279087	279087	274913	249294	259505	216281	259378	284402	216281
E100-15-1-2	442212	282686	272286	263134	272364	263134	263134	263134	272876	263134	253179	246288	228808	251391	266710	228808
E100-15-1-3	466588	308898	289818	289818	289818	289818	289818	289818	289818	289818	279590	282910	256612	285293	292624	256612
E100-15-1-4	487461	311066	291152	297504	314550	291152	291152	305664	297966	291152	283927	277197	257046	284858	288503	257046
E100-15-1-5	436807	304001	287553	283449	296009	283449	283449	287553	296009	283449	272035	265988	244535	283202	287015	244535
E100-15-1-6	451274	304511	283569	286617	286617	283569	283569	283569	286617	283569	284657	274790	246842	282211	290412	246842
E100-15-1-7	413953	277543	257889	257889	264825	257889	257889	259253	264825	257889	255433	247896	221567	238996	257963	221567
E100-15-1-8	471401	297071	279017	279017	279017	279017	279017	279017	279017	279017	275167	276993	247913	280670	277295	247913
E100-15-1-9	532807	309871	289771	289771	292221	289771	289771	289771	289771	289771	251590	251658	239394	250923	291741	239394
E100-15-1-10	489558	311839	289133	289133	291623	289133	289133	291623	291623	289133	264484	263538	252922	270321	287784	252922
E100-15-2-1	537015	300921	269775	269775	269775	269775	269775	269775	269775	269775	219547	218240	187588	215858	270047	187588
E100-15-2-2	683659	353810	319350	319350	319350	319350	319350	319350	319350	319350	256711	251647	216123	254266	327793	216123
E100-15-2-3	575605	341643	305871	305871	305871	305871	305871	305871	305871	305871	234516	225427	218089	230541	308731	218089
E100-15-2-4	612728	301257	270323	270323	276305	270323	270323	270323	276305	270323	194639	192111	165939	196182	271342	165939
E100-15-2-5	545454	306440	278892	278892	278892	278892	278892	278892	278892	278892	221492	217430	197269	222006	278096	197269
E100-15-2-6	632763	305771	277697	277697	279201	277697	277697	277697	279201	277697	206032	205334	172818	210967	275143	172818
E100-15-2-7	641744	335127	297491	297491	301795	297491	297491	297491	301795	297491	237844	225499	190534	232826	298282	190534
E100-15-2-8	673242	341117	307789	307789	307789	307789	307789	307789	307789	307789	219555	219701	196231	219912	309138	196231
E100-15-2-9	704209	334144	299414	302930	299926	299414	299414	299414	299414	299414	231217	214652	187672	231974	298195	187672
E100-15-2-10	657636	313188	283896	283896	283896	283896	283896	283896	283896	283896	213570	217167	185160	220038	287986	185160
E100-15-3-1	933517	316048	276840	276840	276840	276840	276840	276840	276840	276840	148611	148969	115237	146498	282491	115237
E100-15-3-2	1027302	353842	306262	306262	306262	306262	306262	306262	306262	306262	178128	179916	149446	177744	303880	149446
E100-15-3-3	934538	334858	290914	290914	290914	290914	290914	290914	290914	290914	156921	170359	137766	159143	302550	137766
E100-15-3-4	745311	287713	251439	251439	251439	251439	251439	251439	251439	251439	150379	133341	123710	139540	250493	123710
E100-15-3-5	1186640	339063	294771	294771	300947	294771	294771	294771	294771	294771	145170	156761	121034	148370	297116	121034

Table B.2 SSQR objective function values for 100-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-15-3-6	986776	314930	277296	277296	277296	277296	277296	277296	277296	277296	153177	149588	132121	151300	276190	132121
E100-15-3-7	1005176	351789	311677	311677	311677	311677	311677	311677	311677	311677	156523	160328	134614	162602	313020	134614
E100-15-3-8	834173	292609	255393	255393	255393	255393	255393	255393	255393	255393	124169	132869	107660	129458	252147	107660
E100-15-3-9	1144665	318389	282791	282791	283879	282791	282791	282791	283879	282791	139382	148152	112445	144134	283217	112445
E100-15-3-10	1096371	330918	291244	291244	299692	291244	291244	291244	291244	291244	136495	137178	103416	145744	290177	103416
E100-15-4-1	2025991	296566	248908	250068	248908	248908	248908	248908	250068	248908	93485	105775	93032	94112	255111	93032
E100-15-4-2	2098400	353201	298253	298253	298253	298253	298253	298253	298253	298253	107268	111782	101178	98078	303738	98078
E100-15-4-3	1811684	330514	282754	282754	284938	282754	282754	282754	282754	282754	121800	118300	98137	105177	280864	98137
E100-15-4-4	2350299	316121	268941	268941	273239	268941	268941	268941	268941	268941	82827	91721	81045	78594	267337	78594
E100-15-4-5	2962117	383210	332948	332948	332948	332948	332948	332948	332948	332948	99956	105185	96495	95851	338477	95851
E100-15-4-6	2197805	343643	293263	293263	293263	293263	293263	293263	293263	293263	92349	106703	89650	100074	289555	89650
E100-15-4-7	2991185	364393	316931	316931	316931	316931	316931	316931	316931	316931	90005	98696	92887	93293	313779	90005
E100-15-4-8	1858104	330590	278530	278530	278530	278530	278530	278530	279490	278530	110130	104682	102834	105487	282388	102834
E100-15-4-9	2273132	348280	298800	298800	298800	298800	298800	298800	298800	298800	109114	115780	102693	105947	299776	102693
E100-15-4-10	1772219	316207	275609	274691	274691	274691	274691	274691	275609	274691	93906	99924	100467	94286	276347	93906

Table B.3 SSQR objective function values for 200-activity instances

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-1-1-1	151678	100019	99803	99803	99803	99803	99803	100139	100139	99683	100139	99683	99683	100139	99985	99683
E200-1-1-2	159080	94995	94995	94995	94995	94995	94995	94995	94995	94995	94995	94995	94995	94995	97828	94995
E200-1-1-3	152127	91257	91257	91257	91257	91257	91257	91257	91257	91257	91257	91257	91257	91257	99665	91257
E200-1-1-4	146719	88471	88399	88071	88519	87999	88071	88399	88447	88071	88732	88570	88071	88655	97837	87999
E200-1-1-5	136454	88712	88568	88568	88568	88568	88568	88568	88712	88568	88712	88568	88568	88712	98782	88568
E200-1-1-6	149282	91760	91760	91760	91760	91760	91760	91760	91760	91760	91760	91760	91760	91760	93040	91760
E200-1-1-7	149921	89751	89625	89625	89625	89625	89625	89625	89625	89625	89625	89625	89625	89625	97601	89625
E200-1-1-8	147765	90715	91165	90715	91165	90715	90715	90715	91165	90715	90915	91015	90715	91215	97521	90715
E200-1-1-9	155435	93705	93705	93579	93897	93579	93579	93897	93897	93579	93579	93579	93579	93579	96859	93579
E200-1-1-10	144034	90204	90348	90204	90348	90204	90204	90348	90348	90204	90348	90348	90204	90348	98638	90204
E200-1-2-1	105024	48252	48988	46552	49174	46616	48598	48704	49970	46580	46640	47762	46030	46852	77222	46030
E200-1-2-2	87439	38969	38175	37767	38427	37575	38621	38193	39009	37559	36011	36326	36469	36448	66911	36011
E200-1-2-3	111456	47868	48462	45242	47070	44804	48092	46574	48728	44772	45768	46017	44728	45233	80168	44728
E200-1-2-4	101520	48202	49312	46860	48818	46968	48784	48076	49126	47046	47441	46878	46700	46797	77510	46700
E200-1-2-5	116970	45888	46326	44972	46356	45422	45528	45738	46622	45452	43846	45179	44943	44077	73586	43846
E200-1-2-6	108539	44935	46041	42229	44209	42791	45171	44381	47121	42671	42826	43338	41608	42795	68825	41608
E200-1-2-7	98337	44221	44585	43179	44019	43009	45545	43521	44825	43215	42166	42528	42302	42332	76095	42166
E200-1-2-8	168943	54171	54731	53757	53787	53293	54787	53091	55185	53839	51759	52382	51906	52461	93525	51759
E200-1-2-9	116757	50545	50265	49195	49327	49069	50859	49097	50563	49107	48685	48924	47883	49442	81509	47883
E200-1-2-10	143400	50348	50234	48584	49722	48564	49834	49320	50086	48314	46998	48500	48121	47846	79708	46998
E200-1-3-1	217520	46198	47226	46516	47286	44696	47442	45712	48670	44628	44364	45103	44022	44371	75246	44022
E200-1-3-2	176276	44948	46966	45138	47126	45308	46610	45208	47580	44826	42748	44174	43457	42725	68954	42725
E200-1-3-3	214561	46887	46861	45573	47427	44963	48051	45677	47521	44923	44498	45386	45802	43919	75293	43919
E200-1-3-4	170129	45063	47463	44383	46145	44513	47049	44851	48103	43953	43579	43079	43359	42835	75547	42835
E200-1-3-5	159030	41156	43562	41780	41808	41536	43486	41576	44640	42026	40303	40691	39194	40657	71707	39194

Table B.3 SSQR objective function values for 200-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-1-3-6	179299	47517	50067	47613	49229	48419	49881	48055	50141	48475	45320	46730	46976	46113	79857	45320
E200-1-3-7	163043	46503	47795	45851	47085	45117	47327	45121	48955	44843	42740	44573	43536	43832	70073	42740
E200-1-3-8	178779	49267	50825	49275	49865	48979	50443	48157	51189	48793	47196	48664	47631	48381	83205	47196
E200-1-3-9	221561	46651	48315	47493	47161	46875	48775	47029	48611	47127	43982	45910	44441	44539	82329	43982
E200-1-3-10	211434	47924	51384	49728	50812	49436	50830	49312	51246	48848	47059	48711	47986	46931	79116	46931
E200-1-4-1	405735	52387	56139	55725	54977	54181	56749	54829	56885	53679	19603	16292	17303	17127	83585	16292
E200-1-4-2	334715	46479	50307	48393	48333	47464	49900	48081	51375	46887	8261	15359	13395	14668	76097	8261
E200-1-4-3	300727	44131	47891	46097	46707	44563	47335	44785	48829	44785	10230	15344	16284	16134	73869	10230
E200-1-4-4	257683	42975	46329	44213	46039	44123	46681	45793	48117	44739	9520	15710	15884	15884	70857	9520
E200-1-4-5	328627	49857	53589	51401	52647	50109	53703	52719	53919	51141	11074	49227	16179	48407	75887	11074
E200-1-4-6	403602	51212	55690	53728	53738	54138	56428	53958	56108	53036	7939	7939	15809	13037	79618	7939
E200-1-4-7	351064	49594	52764	51246	52576	49516	54228	51578	54184	51180	10192	15775	16466	12926	80602	10192
E200-1-4-8	322086	48454	53566	52762	53010	51274	54008	52070	53002	51134	10182	16526	15373	15157	78070	10182
E200-1-4-9	328092	46320	50478	48958	49792	47656	50722	48304	51698	47512	10847	16469	17412	15389	83596	10847
E200-1-4-10	360237	52833	57711	55927	55847	55315	58375	54557	57955	55105	11209	16195	17074	15814	84761	11209
E200-5-1-1	308149	218241	203913	203797	206433	203185	204407	204103	208415	203185	218465	219444	212789	219643	297322	203185
E200-5-1-2	283781	205405	191427	192113	194273	191169	191905	190333	194149	191169	205617	205655	201009	203034	274195	190333
E200-5-1-3	297504	209728	199526	197410	202522	197410	197818	198690	204664	197410	209343	206847	204610	208559	283136	197410
E200-5-1-4	303141	207941	197127	196715	203553	196715	196725	196715	202423	196715	205723	205124	203748	207552	284907	196715
E200-5-1-5	242967	186215	175033	175881	179223	175033	175129	175943	180075	175033	188035	188035	144822	188405	238785	144822
E200-5-1-6	276305	203065	192789	190043	190467	190467	191241	190701	192789	189887	201387	202987	198341	202303	253323	189887
E200-5-1-7	273826	197938	189996	188260	191152	186870	187660	190900	191002	187180	199580	197476	168973	198750	267962	168973
E200-5-1-8	270588	196997	186742	186322	187612	186132	186424	187866	187656	186132	198870	195653	194278	198664	266568	186132
E200-5-1-9	289059	209109	197047	196391	197231	196391	197089	197543	198367	196391	264577	266543	205659	212221	277395	196391
E200-5-1-10	285604	206154	197548	197052	203676	197052	197782	197782	198750	197782	280978	206860	204420	217177	266302	197052
E200-5-2-1	412158	193554	177472	175906	176816	175790	178106	175698	178304	175926	195848	194322	188258	212807	263256	175698
E200-5-2-2	495137	198917	181305	179691	181307	180467	181307	180117	181041	180795	196557	198503	193561	198171	278853	179691
E200-5-2-3	534283	201313	186925	187055	187641	186883	187441	187441	187735	186735	201198	200507	297579	200531	261623	186735
E200-5-2-4	486316	201422	184572	182894	184616	183126	183408	182842	185002	183310	200784	200650	196772	214647	271194	182842
E200-5-2-5	430036	201352	184002	182186	183436	182316	183940	181986	182932	182232	197722	197674	195450	205224	277466	181986

Table B.3 SSQR objective function values for 200-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-5-2-6	512489	218793	203295	201619	202861	201465	202953	204373	204417	202057	219577	219845	214397	220553	304361	201465
E200-5-2-7	465662	197760	183540	181780	183642	182090	183896	183190	183308	182138	197876	197876	192850	199888	287670	181780
E200-5-2-8	472738	188998	170946	170690	171040	170100	171426	171080	171710	169656	185078	187690	182264	186860	249796	169656
E200-5-2-9	571739	208629	189107	187155	187925	187461	188141	187801	189675	187397	207097	204393	199661	207809	292907	187155
E200-5-2-10	482322	218078	201486	198468	200990	199128	200426	200424	202058	199668	219904	217388	212128	220682	278252	198468
E200-5-3-1	917261	209399	185729	183927	185373	182573	186123	183157	186613	182115	204131	205603	204281	207685	266771	182115
E200-5-3-2	662635	198111	180835	178391	179015	176731	180747	176693	180347	176571	196187	196123	192371	196315	257429	176571
E200-5-3-3	659206	216298	197354	192364	196132	193152	195376	191964	197240	192358	215796	213732	209144	213178	296264	191964
E200-5-3-4	808485	215799	193267	190695	196237	189841	192575	192819	195151	188593	211077	210305	209077	212501	258944	188593
E200-5-3-5	881910	213474	191032	188936	191766	190232	192014	189588	190672	190156	212174	210676	208740	211520	279573	188936
E200-5-3-6	846930	214606	196406	193052	194248	191658	193476	193012	196198	191210	211660	212218	211134	212492	289654	191210
E200-5-3-7	1011953	199909	179977	176227	179363	176725	180847	178009	181789	176725	196471	197357	196259	198665	248735	176227
E200-5-3-8	862234	222484	200356	195682	199112	195138	198528	198218	201998	195962	218844	217284	215550	219384	276823	195138
E200-5-3-9	799359	213923	191029	187771	192031	187587	191113	188651	191327	188827	212343	211469	207233	212273	266171	187587
E200-5-3-10	858647	234587	214627	210125	215187	212039	212195	212029	214877	212127	229873	230771	229521	230753	291883	210125
E200-5-4-1	1336121	214821	189027	186189	185013	185147	188297	185499	190927	183815	207639	209129	211919	207419	267289	183815
E200-5-4-2	1512184	222050	198546	191394	195822	192408	197094	195790	198704	193566	213984	216738	216920	213944	276283	191394
E200-5-4-3	1508092	219098	195634	192756	195902	192758	195902	192758	197830	193250	213616	216896	217378	214846	272610	192756
E200-5-4-4	1467848	236538	210736	211182	209262	207932	211186	207678	215892	208260	242308	240087	241910	241611	294310	207678
E200-5-4-5	1450682	216586	190770	189410	194110	187994	194818	189694	196358	187584	211428	213384	211776	212038	269485	187584
E200-5-4-6	1529582	230776	205054	203012	204196	200936	206298	203424	206162	202446	242308	240087	241910	241611	287141	200936
E200-5-4-7	1361380	224292	200548	200746	200080	198068	200978	200348	202442	198068	229763	227657	229386	229102	279073	198068
E200-5-4-8	1313243	215057	188489	182801	188029	182769	189185	186157	191795	183193	220303	218284	219941	219669	267582	182769
E200-5-4-9	1422760	220470	195350	196050	192638	191032	191936	190686	195698	191524	225848	223778	225477	225198	274318	190686
E200-5-4-10	1293228	218812	195758	193264	191116	189422	194850	190846	196560	189798	224150	222095	223781	223505	272255	189422
E200-10-1-1	600358	449154	424718	424718	429470	424718	424718	424718	429470	424718	451832	448560	429470	450846	492194	424718
E200-10-1-2	506462	385176	358078	358078	361808	361808	358078	358078	361808	358078	382893	387985	358078	366913	397240	358078
E200-10-1-3	567390	417864	389122	388792	389122	388792	388792	389122	389122	388792	412982	417794	388792	415238	435498	388792
E200-10-1-4	520523	480174	355299	355299	355299	355299	356169	355299	355299	355299	477328.02	483677	419865	457407	386493	355299
E200-10-1-5	539787	416567	392793	391957	400005	391957	392377	397509	399755	391957	419865	416045	391957	419649	430573	391957

Table B.3 SSQR objective function values for 200-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-10-1-6	566549	415145	388725	389105	388725	389105	389845	389105	388725	389105	412684	418173	389105	395462	429297	388725
E200-10-1-7	559450	398340	373536	373536	381858	373536	373536	373536	385382	373536	401340	401340	373536	400956	395268	373536
E200-10-1-8	551603	401003	375069	374821	382897	374821	374821	375069	382897	374821	398626	403928	374821	381990	442221	374821
E200-10-1-9	548738	389154	365426	365126	365426	365126	365126	365426	365916	365126	388500	388500	365126	390234	414794	365126
E200-10-1-10	564293	411083	385771	385771	392775	385771	385771	388195	392361	385771	413992	413661	385771	439913	429843	385771
E200-10-2-1	825738	394390	357570	356562	357570	356562	356970	357984	357984	356562	391618	391932	387754	391618	424076	356562
E200-10-2-2	937222	398174	358734	358986	358986	358734	359882	358986	359142	358734	366901	382755	367574	376766	391684	358734
E200-10-2-3	948187	392413	356435	354433	355745	354433	355745	354433	355123	354433	403452	420574	378277	377153	387507	354433
E200-10-2-4	1018374	412256	372542	371246	372542	371246	371502	372542	372542	371246	411194	414826	411194	397370	417358	371246
E200-10-2-5	841502	396688	359104	359104	359104	359104	359104	359104	359104	359104	385379	392721	367460	375100	398182	359104
E200-10-2-6	689757	408011	373883	373883	374083	373883	373883	374083	374083	373883	387079	395100	384861	394146	416489	373883
E200-10-2-7	875099	409057	370703	370691	371137	370691	370367	370367	371137	370691	409254	415201	419663	417132	433065	370367
E200-10-2-8	909069	418519	376645	376645	376109	376645	376645	376109	376645	376645	405351	411117	379518	390804	399291	376109
E200-10-2-9	907490	398708	363630	362904	363500	362904	362904	363534	364746	362904	406769	402813	368187	392618	399578	362904
E200-10-2-10	950036	423756	384768	384768	384768	384768	386080	384768	384768	384768	424585	437484	418953	430468	420846	384768
E200-10-3-1	1816579	417099	367659	365837	367633	364481	364757	364557	367621	364395	425906	431311	419601	420069	470573	364395
E200-10-3-2	1765564	407500	363634	361994	364964	361994	361994	361994	365554	361994	404824	406566	401122	406822	394862	361994
E200-10-3-3	1804675	446259	393201	393201	393201	393201	393609	393201	393201	393201	439125	439963	436179	441389	405413	393201
E200-10-3-4	1829904	411358	362514	361610	362514	361610	361610	361494	362668	362668	418040	417244	420864	415896	414358	361494
E200-10-3-5	1689306	432174	382920	382920	381750	382920	384024	381750	382920	382920	439195	438358	442161	436942	452408	381750
E200-10-3-6	1334201	427201	374591	373679	376857	372935	375107	377523	376779	372935	434141	433314	437073	431914	413549	372935
E200-10-3-7	1749924	427028	375082	374874	375094	374874	375268	374874	375268	374874	429850	428009	433817	427739	397258	374874
E200-10-3-8	993032	418276	367912	366398	371486	366398	367912	369688	372532	365846	421040	419236	424926	418973	416456	365846
E200-10-3-9	1541033	454591	399731	399251	420953	399251	399251	399251	421359	399251	457595.97	455635	450045	455348	431299	399251
E200-10-3-10	1941391	436409	382965	382965	382965	382965	382965	382965	382965	382965	439293	437411	432044	437136	414861	382965
E200-10-4-1	2750837	434557	367035	366131	368117	365531	367693	367189	368611	366141	437429	435555	430211	435281	410621	365531
E200-10-4-2	2943829	445045	383347	383215	382557	383215	384293	382933	383019	382865	447986	446067	440594	445786	428957	382557
E200-10-4-3	1002527	433265	374553	372479	374921	372315	371939	371973	374327	371295	436129	434260	428932	433987	424769	371295
E200-10-4-4	3073891	467395	400029	399497	399833	399497	399693	399833	399693	399833	470484	468468	462721	468174	431453	399497
E200-10-4-5	954245	438815	379775	378767	379685	378263	381831	380435	380561	379055	441715	439823	434426	439546	427449	378263

Table B.3 SSQR objective function values for 200-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-10-4-6	3138890	453036	391142	391142	391142	391326	392066	391142	392066	391142	456030	454076	448505	453791.02	435108	391142
E200-10-4-7	2592274	409644	350354	350354	350226	349586	351004	349586	351260	349586	412351	410585	405547	410326	391480	349586
E200-10-4-8	2771720	450730	388052	387676	387250	386616	386906	387848	389042	386988	453709	451765	446222	451481	455266	386616
E200-10-4-9	2614430	422224	361106	361702	361900	359306	359210	359868	364166	359936	425015.02	423193.97	418001	422927	403028	359210
E200-10-4-10	2772978	435170	380534	378852	378970	379908	380408	378852	381334	378852	438046	436169	430818	435895	411100	378852
E200-15-1-1	888407	658809	620485	620485	628199	620485	620485	620485	628331	620485	641857	651753	620485	648433	629281	620485
E200-15-1-2	849431	627941	585239	585239	589475	585239	585239	585239	589475	585239	630923	624827	613735	629713	593669	585239
E200-15-1-3	861929	627599	586917	586917	589989	586917	586917	586917	589989	586917	630581	624485	613393	629371	595469	586917
E200-15-1-4	889335	628659	589617	589617	589617	589617	589617	589617	589617	589617	623670	599347	598453	610698	592999	589617
E200-15-1-5	817530	601642	562696	562696	562696	562696	562696	562696	562696	562696	604624	598528	587436	603414	566888	562696
E200-15-1-6	774921	598423	563571	563571	571659	563571	563571	563571	571659	563571	601423	595009	583923	600423	565583	563571
E200-15-1-7	859201	624961	583505	583505	583505	583505	583505	583505	583505	583505	613861	613861	610461	598119	589483	583505
E200-15-1-8	865430	627834	593764	593764	599076	593764	593764	593764	599076	593764	607392	603760	603334	607392	595010	593764
E200-15-1-9	868069	620125	581439	581439	581439	581439	581439	581439	581439	581439	608660	592101	585625	593111	581439	581439
E200-15-1-10	822971	612709	576371	576371	581179	576371	576371	576371	581179	576371	584528	584030	578209	605804	584019	576371
E200-15-2-1	1271099	642902	581948	581948	588122	581948	581948	581948	593152	581948	598647	596759	580879	598497	545089	545089
E200-15-2-2	1396668	624368	564050	564050	570274	564050	564050	564050	570274	564050	627368	600954	579868	696368	596306	564050
E200-15-2-3	1446214	646782	586128	586128	586128	586128	586128	586128	586128	586128	649782	643368	592282	638782	564050	564050
E200-15-2-4	1428544	633949	570467	570467	583289	570467	570467	570467	576455	570467	636949	630535	589449	625949	586128	570467
E200-15-2-5	1548149	631549	570975	570975	570975	570975	570975	570975	570975	570975	634549	628135	587049	633549	575221	570975
E200-15-2-6	1458107	653388	595242	595242	595242	595242	595242	595242	595242	595242	656388	649974	638888	655388	572815	572815
E200-15-2-7	1393560	621686	557722	557722	557722	557722	557722	557722	557722	557722	624686	618272	597186	623686	608720	557722
E200-15-2-8	1402482	652186	582478	582478	582478	582478	582478	582478	582478	582478	655186	648772	637686	654186	564352	564352
E200-15-2-9	1568361	687299	622901	622901	626051	622901	622901	622901	626051	622901	690299	683885	652799	689299	628353	622901
E200-15-2-10	1749100	667476	605522	605522	605522	605522	605522	605522	605522	605522	670476	664062	642976	669476	606850	605522
E200-15-3-1	2727806	635198	561070	561070	561070	561070	561070	561070	561070	561070	638198	631784	590698	637198	562102	561070
E200-15-3-2	2298315	613739	545109	545109	545109	545109	545109	545109	545109	545109	616739	610325	599239	615739	546817	545109
E200-15-3-3	2606244	630522	555038	555038	555038	555038	555038	555038	555038	555038	633522	627108	616022	632522	555038	555038
E200-15-3-4	2329706	642486	559836	559836	559836	559836	559836	559836	559836	559836	645486	639072	627986	644486	561372	559836
E200-15-3-5	2286783	602239	529211	529211	529211	529211	529211	529211	529211	529211	605239	598825	587739	604239	529211	529211

Table B.3 SSQR objective function values for 200-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-15-3-6	2597411	646707	575911	571339	586685	571339	571339	578127	579541	571339	649707	643293	632207	648707	574803	571339
E200-15-3-7	2651397	677681	602921	600631	606603	600631	600631	600631	603065	600631	737929	658732	609475	666557	600631	600631
E200-15-3-8	2771785	613855	544335	543375	544335	543375	544335	543375	544335	543375	607781	612056	593746	606541	556029	543375
E200-15-3-9	2416202	664073	618478	618478	618478	618478	618478	618478	618478	618478	647036	650600	610090	653679	619768	610090
E200-15-3-10	2409406	648624	573112	573112	578296	573112	573112	573112	578296	573112	638481	635927	609154	635873	573948	573112
E200-15-4-1	4193232	653504	555010	555010	555010	555010	555010	555010	555010	555010	640002	644996	641512	637048	562684	555010
E200-15-4-2	3820544	639238	546972	546076	546076	546076	546972	546836	546972	546076	625176	626158	629044	624698	553844	546076
E200-15-4-3	4706971	686147	583225	582227	582227	582227	582227	582227	582227	582227	672977	677135	676751	668707	589181	582227
E200-15-4-4	4987941	670127	579987	579315	579787	579315	579987	579315	579315	579315	653981	658345	663399	656187	581783	579315
E200-15-4-5	3918551	649029	560461	560461	560461	560461	560461	560461	560461	560461	635811	638357	637639	642715	563329	560461
E200-15-4-6	4345321	669619	575113	575113	578469	575113	575113	575113	575113	575113	661265	661957	657879	658913	580309	575113
E200-15-4-7	3970708	650806	560324	560324	560324	560324	560324	560324	560324	560324	641936	641984	646384	640146	560324	560324
E200-15-4-8	4129390	625524	526948	527388	527388	526948	527602	526948	527602	526948	607928	613178	609154	609398	528426	526948
E200-15-4-9	3747628	648138	552668	552668	552668	552668	552668	555248	555248	552668	632180	643176	637184	631394	554768	552668
E200-15-4-10	4922244	644190	554764	554764	556504	554764	554764	554764	554764	554764	630598	636986	639162	632940	557904	554764

Table B.4 SSQR objective function values for 500-activity instances

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 1-1-1	236251	112639	112959	111587	114049	110385	112465	112093	114437	110555	111855	112069	110265	112423	192139	110265
E500 1-1-2	272844	110054	109590	109454	111450	109072	110242	109462	111764	108358	109502	110278	107926	109394	203640	107926
E500 1-1-3	223990	125240	125176	122504	124814	122366	124650	124008	125708	122158	123594	124010	121094	124334	214122	121094
E500 1-1-4	227124	114938	115548	112590	115996	112684	114646	114360	116874	112572	114798	115308	111670	114990	205194	111670
E500 1-1-5	209439	113277	114101	111425	113789	110669	113641	113133	115283	110923	112943	112719	111103	113565	194017	110669
E500 1-1-6	217378	108456	109100	108632	109172	109050	109498	108898	109222	109242	108144	108156	107050	108556	207462	107050
E500 1-1-7	181697	113209	114213	110783	114359	110411	113759	114055	114679	110661	113415	113105	110079	113475	171355	110079
E500 1-1-8	204981	118151	118407	115835	118367	115147	117267	117137	119109	114963	116711	117277	114047	116333	184891	114047
E500 1-1-9	226144	112088	112372	111980	113234	110594	112626	111738	113788	110978	111852	113110	110262	111266	196570	110262
E500 1-1-10	163031	108065	107921	106037	108173	105637	107661	106831	108555	105787	106677	106751	104975	107207	149401	104975
E500 1-2-1	323952	115058	118076	114560	116750	114200	117896	117212	118938	114896	115220	115532	113456	115642	191566	113456
E500 1-2-2	331767	114893	117561	111025	117457	110735	115665	115385	119079	110765	111579	112587	109003	112283	207655	109003
E500 1-2-3	307389	111677	114085	108333	112829	107457	113323	111235	115085	107525	110141	110779	106995	109655	190498	106995
E500 1-2-4	349589	121933	123365	119439	123709	118877	123477	122085	124365	119503	120709	121047	116647	121571	225620	116647
E500 1-2-5	251492	111814	112668	110298	111944	109380	112698	111354	114444	109606	109662	110280	107856	109832	191167	107856
E500 1-2-6	367222	119072	121368	118282	122352	117042	120766	120538	122464	117344	117974	117944	114904	118576	212574	114904
E500 1-2-7	348019	119913	121949	120345	122229	119503	121751	121107	122137	119587	118971	118993	116987	119543	226554	116987
E500 1-2-8	309895	116193	117883	114475	117731	113847	117537	115909	119233	114627	114365	115463	113147	114897	222261	113147
E500 1-2-9	286496	122960	125024	122214	126046	122978	125460	124072	127108	123014	122886	121086	119536	122906	218698	119536
E500 1-2-10	404922	124240	125206	121926	124230	121036	124324	123948	126438	122170	122616	121640	120550	122330	225965	120550
E500 1-3-1	304945	119093	123263	117515	120689	115663	121583	116739	123811	115969	116135	116579	113767	116355	208854	113767
E500 1-3-2	346142	131750	136476	129368	133606	127762	136046	131954	137114	127676	129494	131764	129574	130544	243104	127676
E500 1-3-3	335661	124707	129625	124447	126451	123835	129479	124753	129923	122985	120667	122797	120731	121903	207631	120667
E500 1-3-4	369625	130619	136345	128641	132069	127057	133811	130331	135957	126375	126727	128689	124629	128111	236077	124629
E500 1-3-5	309700	121900	124334	118232	123120	117698	123104	120048	125896	118044	118942	119116	117100	119170	218332	117100

Table B.4 SSQR objective function values for 500-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 1-3-6	293298	117096	119976	116172	119874	115008	119324	115734	121618	114848	114668	114956	113674	115896	209684	113674
E500 1-3-7	363384	132100	135974	130740	134302	129952	134454	131444	135742	129852	127806	131020	128482	128532	236502	127806
E500 1-3-8	353598	123590	129758	122566	127424	122240	128132	125422	130062	122006	121806	123916	121432	121978	221221	121432
E500 1-3-9	341466	124042	126604	121236	125818	120020	126120	122476	128180	119090	120674	121444	118172	120054	221984	118172
E500 1-3-10	326980	127320	132418	128728	129666	125732	132026	127736	132908	127268	125410	127384	126688	126876	227802	125410
E500 1-4-1	877972	127158	139944	132250	133628	132864	139394	132598	139606	131406	124546	126530	127514	125096	227465	124546
E500 1-4-2	914912	129746	143562	134618	137216	134142	141628	135930	142470	133324	126888	129638	128698	126854	232047	126854
E500 1-4-3	936757	126693	138571	131661	136279	130025	137521	131611	140119	130977	125295	127323	127385	124559	226539	124559
E500 1-4-4	889429	127715	138771	130105	133471	128919	138907	131731	139761	130975	123719	125855	126779	124555	228319	123719
E500 1-4-5	877461	123735	134035	127525	132173	127079	133441	128793	135941	125133	119513	121247	120589	119597	221158	119513
E500 1-4-6	815782	126368	135084	129934	133906	130146	137428	129838	137526	130898	124612	125300	125646	123260	225817	123260
E500 1-4-7	832115	126611	138555	130327	132439	129901	136819	132381	139039	129197	124137	124451	125805	122743	226204	122743
E500 1-4-8	804901	122719	134277	127033	130131	125743	133963	129073	133939	126519	118479	121263	122849	119381	219205	118479
E500 1-4-9	898477	127789	139993	131989	133713	130517	137755	130879	139599	130555	125187	127141	127039	124473	228214	124473
E500 1-4-10	885263	129667	139577	133199	134483	132283	140839	133997	140431	132847	126757	128409	128691	126271	231519	126271
E500 5-1-1	943050	323691	480580	478656	513272	478986	479852	479058	515176	478684	358183	353373	344019	355213	440982	323691
E500 5-1-2	778061	344197	493587	490195	495791	489233	491213	488973	497649	489105	352361	342122	315430	350163	459468	315430
E500 5-1-3	765835	333367	463544	461274	467948	461278	462668	463026	468090	461398	338561	334091	325490	336609	450051	325490
E500 5-1-4	696194	341036	467345	467275	469355	466279	467981	466167	467771	466369	340961	336674	331510	342365	467265	331510
E500 5-1-5	712071	354690	478618	475994	480626	476354	477594	478856	482328	475610	363886	357932	339726	364960	511964	339726
E500 5-1-6	687869	330275	467081	465633	480649	466059	466885	466623	481519	466259	331428	323618	321182	330270	477075	321182
E500 5-1-7	756642	335271	478608	476854	480496	476028	478970	477270	481258	476532	331391	331826	319346	332124	453879	319346
E500 5-1-8	679291	344442	467651	464207	466345	464111	466271	465959	467675	463247	344322	339437	329136	346038	483569	329136
E500 5-1-9	669972	350133	487353	482363	489851	480961	483273	484567	489801	481483	354738	352389	323843	356230	464471	323843
E500 5-1-10	741790	339046	469395	467277	470985	466335	469145	470057	470127	466775	345244	337235	328507	343457	437967	328507
E500 5-2-1	1323856	373889	468420	463162	471188	463816	466930	467102	472952	464336	371484	369818	350963	372934	508533	350963
E500 5-2-2	1213127	365770	488559	485449	488843	485145	488669	488803	489467	486115	373912	371894	355463	375338	512757	355463
E500 5-2-3	1353359	389446	500130	498738	502400	497546	499456	499362	501060	497190	389304	390633	369150	394654	506117	369150
E500 5-2-4	1224529	371834	484183	480469	488099	480537	483781	484681	488597	480817	371264	366960	354304	378741	500636	354304
E500 5-2-5	1158289	359485	472520	472284	472602	470438	473634	471124	477760	471062	355104	358347	348624	358207	495376	348624

Table B.4 SSQR objective function values for 500-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 5-2-6	1383237	381478	497136	490164	492472	489818	492726	493936	496722	490074	382712	378461	358210	378307	530671	358210
E500 5-2-7	1316519	366402	470111	468029	472013	467195	469377	469347	472805	466297	367984	362896	349228	373508	532984	349228
E500 5-2-8	1166725	374451	478525	471875	496891	470323	477517	472837	497779	471045	377224	371295	352369	379080	494907	352369
E500 5-2-9	1343664	374578	494868	489488	493994	488716	492792	492262	496566	489016	375997	375893	357064	382291	525893	357064
E500 5-2-10	1143824	360489	463915	456801	459661	457009	462583	460159	463183	456737	360198	356839	346092	364291	459958	346092
E500 5-3-1	1415340	406616	494678	488324	491700	491132	494320	491210	494798	490076	399393	403631	393135	401461	518022	393135
E500 5-3-2	1317767	402252	486489	484259	495063	481435	488037	482745	495835	481487	386894	396075	381363	397106	522693	381363
E500 5-3-3	1415530	410606	498134	493702	499770	490586	497456	493766	502604	492004	397760	399556	389836	406035	562408	389836
E500 5-3-4	1414732	413379	499780	496640	508934	496920	497594	499562	511474	498126	406991	406041	392220	415164	496026	392220
E500 5-3-5	1367761	400043	472723	462579	470339	464447	468043	463657	475255	464357	387438	392271	378372	399248	523910	378372
E500 5-3-6	1336936	401883	477662	470238	475880	469846	476772	471520	484770	472596	398150	399594	386027	400993	542422	386027
E500 5-3-7	1417518	405948	475000	471930	483928	471102	474306	474796	479726	471822	397908	391798	385337	402783	505097	385337
E500 5-3-8	1381944	395681	471122	466372	470504	466506	467760	469990	478162	465782	384796	389504	361857	392066	492321	361857
E500 5-3-9	1462742	408858	506602	501926	524064	499182	505854	503048	520046	499650	395804	397755	386885	396748	508718	386885
E500 5-3-10	1293327	401886	487439	485427	494277	486497	489095	486223	496253	485095	385473	376668	372098	391240	500043	372098
E500 5-4-1	3682938	440819	512584	504638	507402	505514	512564	501924	513642	504860	420332	425406	438156	428223	548485	420332
E500 5-4-2	3477013	461677	516317	516317	512577	505329	514127	509447	517103	504643	435752	447567	439937	435351	574436	435351
E500 5-4-3	3682496	455459	514274	505840	509386	504484	512136	504856	516220	505138	419386	432162	436290	428444	566699	419386
E500 5-4-4	3658038	453825	516168	506096	510656	503174	515672	507908	515064	504016	434360	438526	445468	438392	564667	434360
E500 5-4-5	3356764	439107	510802	501458	506866	500798	511564	499848	510614	499032	421910	422923	423311	417255	546355	417255
E500 5-4-6	3615538	448646	507380	498322	503090	497922	506194	499582	508850	499502	432742	424542	438726	423679	558224	423679
E500 5-4-7	3350918	439439	475723	461113	469585	458789	469477	464463	472821	460645	411545	406841	422431	408224	546767	406841
E500 5-4-8	3350918	436797	485726	478296	482414	475474	485502	479794	485070	475970	409950	416267	422898	420774	543481	409950
E500 5-4-9	3148343	440101	475671	458287	463837	454155	468665	458477	476849	456297	408011	414194	421864	409281	547592	408011
E500 5-4-10	3420806	438685	489124	482774	489120	480076	492004	482468	492542	479474	421683	418802	427885	416513	545830	416513
E500 10-1-1	1645130	623317	942077	942693	972443	942233	942569	942251	972767	942557	627208	628532	598934	628343	683046	598934
E500 10-1-2	1507707	601510	928781	927791	929119	927967	928477	928471	929247	927791	601344	590163	559249	602957	620350	559249
E500 10-1-3	1432844	609660	972172	972596	979232	972596	972596	972172	978752	972596	602624	605078	562316	611250	635388	562316
E500 10-1-4	1821881	610543	1011784	1011390	1017752	1011390	1011390	1011784	1018408	1011390	596167	594562	555685	597870	601427	555685
E500 10-1-5	1659809	609660	963547	964419	1000261	963547	963547	1009689	1009689	963547	605599	614018	585730	611509	630158	585730

Table B.4 SSQR objective function values for 500-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 10-1-6	1564390	590592	918453	918231	927167	918231	918231	918453	927167	918231	595647	593753	572151	597554	610725	572151
E500 10-1-7	1591517	605241	995688	995688	996552	995688	995688	995688	996552	995688	605638	608190	552990	607259	600573	552990
E500 10-1-8	1524357	588653	939338	939170	1000398	939170	939338	939338	1000398	939338	584197	583623	562530	587321	649159	562530
E500 10-1-9	1749610	590911	1006969	1006417	1006969	1006417	1006765	1006969	1006969	1006765	554792	555495	541568	557109	629844	541568
E500 10-1-10	1464503	605775	947773	947145	991547	947145	947145	947691	991283	947145	630632	606722	579055	615448	633420	579055
E500 10-2-1	2581782	660218	932547	933119	951495	933033	934143	932547	952123	933161	668222	663474	625583	669858	709913	625583
E500 10-2-2	2114577	639235	977529	977419	977529	977419	977529	977419	977529	977419	629455	626886	606299	642566	628816	606299
E500 10-2-3	2826712	640052	962137	961695	987491	960751	962061	962061	983453	961167	645955	647079	614530	656521	632050	614530
E500 10-2-4	2614809	643792	947714	947210	961136	947210	947210	951494	961260	947210	639556	639806	611943	645038	651759	611943
E500 10-2-5	2346222	687680	955808	955350	960994	955350	955896	955896	959610	955350	681898	687398	637122	685156	690270	637122
E500 10-2-6	2893322	661220	966458	963252	965926	963252	964256	963696	967358	963848	663078	659177	629666	665859	674959	629666
E500 10-2-7	2054373	634322	967955	967595	990109	966131	969127	966503	966503	966263	636766	625958	594415	648701	671551	594415
E500 10-2-8	2504782	662385	968589	968097	970291	968097	968287	968779	968779	968097	668335	657060	620605	668168	631953	620605
E500 10-2-9	2918358	649135	911298	908230	916374	907682	908678	910568	918240	907098	646347	651123	612918	653231	650551	612918
E500 10-2-10	2641336	665223	967842	967842	972276	967842	967842	967842	973696	967842	664110	660439	628532	665150	660655	628532
E500 10-3-1	2812070	731892	959986	955334	965364	955266	955478	955334	970414	955334	709772	714308	680008	707453	825724	680008
E500 10-3-2	2739491	738399	941767	939415	944731	938735	940807	939503	945859	939313	718627	713821	686191	730150	715499	686191
E500 10-3-3	2900326	720874	988154	986924	1007862	988032	987644	986484	1009382	987252	698892	705899	673906	707954	674893	673906
E500 10-3-4	2773514	734575	953016	951368	965328	952110	952576	951128	965950	951128	720881	718975	682407	721110	739932	682407
E500 10-3-5	2773927	697297	967873	963365	967873	964535	966021	965905	967873	964535	702798	715871	671341	716911	729944	671341
E500 10-3-6	2772937	730970	959267	958909	993851	959815	959267	960049	991085	959135	686083	707881	673462	704163	707610	673462
E500 10-3-7	2435816	734194	920742	918166	925052	918420	920166	917640	928962	919596	695991	701380	662951	706080	683010	662951
E500 10-3-8	2902731	741044	941067	937355	940925	940925	942903	935605	944957	935171	731110	728148	687450	726324	737820	687450
E500 10-3-9	2615573	728179	906695	906551	918495	906695	906695	906551	918495	906551	696580	705865	689154	719032	690869	689154
E500 10-3-10	2717826	728162	939948	939160	941784	939128	939948	939948	942888	938024	702717	702714	678585	708472	692208	678585
E500 10-4-1	7269201	839783	986109	983273	984923	983099	987057	983307	986389	980739	764537	801212	818227	783272	793527	764537
E500 10-4-2	6728106	834690	928944	925160	929344	925374	929016	925374	930076	926248	773199	791646	782183	766631	804517	766631
E500 10-4-3	7241112	811829	970024	961272	967598	962956	974410	964224	970108	963130	783004	787547	790031	780002	795910	780002
E500 10-4-4	6798344	826712	925020	923562	922592	920498	925178	923488	925898	922982	768477	780846	793969	769483	769139	768477
E500 10-4-5	7133164	822812	937342	936264	938694	934392	938278	933506	938720	933788	771722	785761	791216	767554	801500	767554

Table B.4 SSQR objective function values for 500-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 10-4-6	7018930	850679	982666	981354	982140	981244	982646	981394	982790	980720	784384	789639	821226	778937	817015	778937
E500 10-4-7	7133831	823694	946113	943243	946489	943601	946355	944289	947423	943141	760917	791311	765810	765420	787171	760917
E500 10-4-8	6315393	817310	910423	909059	910029	907851	908593	908163	910815	908035	761776	769481	772711	771587	825535	761776
E500 10-4-9	6947077	827827	965187	964681	965973	963203	965975	965385	967985	965385	758262	784535	787208	768600	790191	758262
E500 10-4-10	7061898	838314	961938	960112	961088	959980	959658	959180	960580	959858	737265	794698	804264	776794	791945	737265
E500 15-1-1	2503488	938907	1397804	1397804	1542394	1397804	1397804	1397804	1542394	1397804	944078	946807	913934	949563	924119	913934
E500 15-1-2	2268663	932753	1443049	1443049	1576051	1443049	1443049	1566969	1576051	1443049	938850	938727	895078	945683	935385	895078
E500 15-1-3	2200292	936631	1449488	1449488	1552862	1449488	1449488	1452718	1490360	1449488	935383	940398	891678	940532	939275	891678
E500 15-1-4	2602733	929410	1430655	1430655	1431355	1430655	1430655	1430655	1431355	1430655	928865	934715	905323	931593	905856	905323
E500 15-1-5	2075070	932721	1439025	1439025	1443853	1439025	1439025	1439025	1443853	1439025	936177	943460	904169	941887	935468	904169
E500 15-1-6	2380600	928161	1445990	1445990	1726582	1445990	1445990	1445990	1726582	1445990	926782	936569	907515	932498	931263	907515
E500 15-1-7	2131981	935047	1417483	1417483	1496607	1417483	1417483	1496607	1496607	1417483	936775	928872	903314	936716	904886	903314
E500 15-1-8	2243872	927506	1376845	1376845	1444633	1376845	1376845	1376845	1384833	1376845	947776	933251	895991	948325	897306	895991
E500 15-1-9	2329712	918258	1417353	1417353	1578951	1417353	1417353	1417353	1578951	1417353	917348	913801	902365	916269	908256	902365
E500 15-1-10	1819518	904380	1331002	1331002	1331846	1331002	1331002	1331002	1331846	1331002	911263	909366	874931	920758	894187	874931
E500 15-2-1	3920484	1031042	1413572	1413572	1450810	1413572	1413572	1413572	1450810	1413572	1034103	1037057	974049	1039025	979828	974049
E500 15-2-2	3652747	992186	1378589	1378589	1420011	1378589	1378589	1378589	1415681	1378589	988766	992667	940140	1006884	1106601	940140
E500 15-2-3	3652283	1015520	1393733	1393733	1397465	1393733	1393733	1393733	1397465	1393733	1012780	1018849	960860	1019616	1002959	960860
E500 15-2-4	3785304	1024246	1429665	1429665	1450409	1429665	1429665	1429665	1450409	1429665	1020768	1016674	978124	1020399	1011320	978124
E500 15-2-5	4189306	1010333	1411673	1411237	1418573	1411237	1411673	1411237	1418573	1411237	1014811	1011330	958020	1029450	1013532	958020
E500 15-2-6	4002796	1010967	1479742	1479214	1531542	1479214	1479742	1479742	1532070	1479742	1010611	1007719	957618	1017899	1014061	957618
E500 15-2-7	3784161	1010713	1371629	1371629	1371629	1371629	1371629	1371629	1371629	1371629	993797	1000216	961460	1002897	1013964	961460
E500 15-2-8	3757192	1023599	1435682	1435682	1437656	1435682	1435682	1435682	1437656	1435682	1030773	1019230	983429	1040486	1026738	983429
E500 15-2-9	3610372	1005920	1411576	1434772	1411576	1411576	1411576	1411576	1434772	1411576	986720	1002501	949172	1006215	1008847	949172
E500 15-2-10	3593693	1006352	1468773	1468773	1490293	1468773	1468773	1476967	1485499	1468773	1009110	998798	965317	1011194	1009367	965317
E500 15-3-1	4278283	1119439	1446497	1446497	1460061	1446497	1446497	1446497	1460061	1446497	1083013	1093224	1033715	1108347	1122963	1033715
E500 15-3-2	4448048	1130994	1447538	1447538	1468298	1448204	1448204	1447538	1468298	1447538	1088042	1106705	1066005	1106998	1134679	1066005
E500 15-3-3	3974016	1088255	1383298	1383298	1393938	1383298	1383298	1383298	1393938	1383298	1064678	1070567	1025077	1075053	1091706	1025077
E500 15-3-4	4336812	1129382	1428002	1428002	1428002	1428002	1428002	1428002	1428002	1428002	1093721	1129346	1047931	1116954	1132897	1047931
E500 15-3-5	3789065	1104633	1379393	1379393	1409405	1379393	1379393	1379393	1409405	1379393	1069284	1077038	1026055	1071205	1108301	1026055

Table B.4 SSQR objective function values for 500-activity instances (cont'd)

Project Name	SSQR Objective Function Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	UB
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 15-3-6	4296547	1097383	1454771	1454771	1465529	1454771	1454771	1454771	1465529	1454771	1059314	1090390	1031773	1072322	1100776	1031773
E500 15-3-7	4198475	1115717	1395467	1395467	1406371	1395467	1395467	1395467	1406371	1395467	1088415	1093941	1035041	1095210	1097402	1035041
E500 15-3-8	4356684	1132853	1403512	1404104	1412576	1403328	1404288	1403328	1410728	1403512	1104169	1115564	1039690	1118090	1119355	1039690
E500 15-3-9	4134612	1117599	1400260	1400260	1400836	1400260	1400260	1400260	1400836	1400260	1098719	1099440	1033229	1115050	1100106	1033229
E500 15-3-10	4485687	1121921	1496053	1496053	1510061	1496053	1496053	1496053	1510061	1496053	1085508	1106603	1042702	1097643	1099865	1042702
E500 15-4-1	10935398	1276333	1471966	1472830	1472830	1471966	1471966	1471966	1471966	1471966	1155386	1152746	1178376	1186306	1244193	1152746
E500 15-4-2	10291630	1269602	1428426	1428426	1428426	1428426	1428426	1428426	1428426	1428426	1190240	1218112	1218428	1201105	1240723	1190240
E500 15-4-3	10447878	1272189	1434030	1433200	1433200	1433200	1433200	1433200	1433200	1433200	1196662	1217225	1213021	1186320	1239853	1186320
E500 15-4-4	9939882	1279341	1413792	1413376	1413792	1413376	1413792	1414112	1413792	1413376	1202529	1227251	1212329	1212886	1252728	1202529
E500 15-4-5	10782221	1272944	1480161	1478613	1480161	1478613	1480161	1478613	1480161	1478613	1200452	1210159	1204733	1200085	1260560	1200085
E500 15-4-6	10011203	1281551	1389945	1389279	1389945	1389279	1389279	1389279	1389945	1389279	1190615	1220156	1243125	1180974	1261061	1180974
E500 15-4-7	11144458	1261540	1486104	1486308	1489622	1485804	1485804	1485804	1489622	1485804	1187883	1229817	1239435	1194366	1240876	1187883
E500 15-4-8	9214068	1182531	1348506	1348506	1348506	1348506	1348506	1348506	1348506	1348506	1121432	1134052	1125733	1129909	115204	1121432
E500 15-4-9	10649899	1272007	1459453	1457493	1457493	1459453	1457493	1457493	1457493	1457493	1176322	1219761	1211045	1184506	1239146	1176322
E500 15-4-10	9935679	1255567	1358981	1357197	1362351	1357049	1359117	1357049	1360517	1357197	1174650	1206413	1194465	1187250	1233640	1174650

APPENDIX C

SSQR OBJECTIVE FUNCTION DEVIATIONS

Table C.1 SSQR obj. function deviations from UB for 50-activity instances

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E50 1-1-1	15.68	20.43	21.45	20.87	15.29	18.68	19.92	21.77	17.87	0	7.56	4.03	8.16	64.15
E50 1-1-2	2.34	8.15	4.37	10.37	4.63	12.23	10.35	7.79	5.58	2.05	1.11	0.35	0	62.08
E50 1-1-3	5.41	16.57	13.79	15.57	9.64	22.18	18.2	13.11	13.51	0	3.11	2.8	1.15	58.16
E50 1-1-4	5.59	13.3	12.5	14.53	8.02	12.32	12.13	14.61	7.05	0	8.66	5.13	4.5	63.44
E50 1-1-5	10.77	16.18	14.61	21.44	13.47	14.43	16.2	22.16	13.75	6.18	7.44	6.85	0	81.73
E50 1-1-6	3.68	8.85	6.44	6.78	9.59	10.7	8.85	7.87	8.77	0	2.8	3.54	0.65	47.86
E50 1-1-7	7.86	17.89	13.32	15.16	6.05	11.53	14.14	15.6	11.43	3.61	1.3	0	0	77.21
E50 1-1-8	0	12	14.56	11.63	14.11	9.72	11.16	14.09	7.45	0	5.01	2.1	1.46	74.27
E50 1-1-9	10.56	12.74	14.33	17.48	14.49	19.88	17.63	20.45	15.81	0	2.78	7.9	7.9	76.91
E50 1-1-10	2.75	11.45	11.68	14.15	6.99	9.81	12.29	12.78	6.04	1.22	4.36	3.91	0	65.42
E50 1-2-1	9.08	16.36	19.5	22.24	12.68	18.25	16.24	17.84	10.78	7.13	8.45	0	5.76	55.43
E50 1-2-2	1.59	12.33	9.14	11.77	10.62	15.04	9.89	16.13	13.4	0	6.88	6.27	6.27	82.1
E50 1-2-3	5.36	6.66	8.62	9.99	4.15	7.57	6.65	10.09	3.99	2.79	4.85	7.93	0	60.2
E50 1-2-4	2.97	11.89	9.29	14.9	7.75	11.85	15.27	13.31	6.07	0	1.1	0.48	2.15	56.05
E50 1-2-5	11.29	17.6	28.57	28.8	24.76	12.96	23.28	26.98	24.28	3.92	4.6	0	5.94	83.22
E50 1-2-6	5.31	7.41	9.32	9.45	3.9	11.01	7.2	10.96	5.26	4.54	2.7	1.62	0	71.23
E50 1-2-7	4.76	13.77	5.77	15.93	10.46	11.15	18.1	16.17	9.11	1.68	0	1.7	5.01	71.08
E50 1-2-8	18.45	4.23	6.61	3.88	6.2	2.11	3.45	6.18	0	19.64	21.23	18.1	17.95	120.2
E50 1-2-9	3.67	9.46	7.63	9.27	6.64	9.55	8.57	8.87	9.74	0.08	0	1.67	2.54	57.57
E50 1-2-10	3.05	8.85	9.12	11.81	8.15	10.7	10.93	11.73	7.92	0.44	3.26	0	0.91	62.65
E50 1-3-1	6.66	17.48	16.99	16.77	20.79	17.01	15.31	20.5	12.86	0	4.99	3.91	3.8	65.91
E50 1-3-2	4.23	11.52	7.88	5.56	9.55	17.62	7.75	14.69	9.22	0	5.41	3.21	1.13	84.98
E50 1-3-3	2.94	7.87	2.29	7.01	2.44	8.69	6.81	11.38	4.96	1.03	3.7	1.48	0	62.18
E50 1-3-4	2.05	4.67	5.43	8.17	2.29	6.3	4.41	6.41	6.1	0	3.66	0.33	1.45	61.64
E50 1-3-5	1.13	9.72	6.37	8.05	9.1	12.65	8.29	15.43	6.19	0.91	5.01	0	1.46	54.83
E50 1-3-6	1.15	10.75	3.66	7.34	5.48	10.08	8.12	10.13	8.12	0	4.52	0.6	0.42	49.93
E50 1-3-7	4.77	8.99	6.78	8.98	1.96	12.72	11.44	13.92	6.24	0	5.9	1.02	1.11	51.91
E50 1-3-8	6.19	8.34	9.62	9.06	10.68	11.91	8.24	14.3	11.58	0.65	0	3.18	5.71	54.61
E50 1-3-9	4.64	13.29	18.52	16.5	8.79	14.35	9.43	19.71	11.23	2.09	6.09	3.89	0	40.48
E50 1-3-10	2.26	11.34	11.85	15.39	3.97	12.01	10.03	14.61	2.83	1.13	0	3.5	7.35	52.2
E50 1-4-1	4.06	12.03	11.52	6.66	6.63	12.6	10.43	14.71	5.1	0	3.44	1.55	0.16	87.09
E50 1-4-2	9.87	18.07	16.4	20.51	13.8	18.62	11.68	19.64	13.65	5.23	5.56	0	6.27	42.06
E50 1-4-3	3.42	7.71	11.47	13.62	1.64	15.54	4.08	14.2	4.61	0	3.98	0.27	0.9	63.35
E50 1-4-4	4.66	9.58	11.48	12.94	7.39	12.52	11.16	13.15	5.51	2.01	1.06	0.74	0	107.8
E50 1-4-5	16.05	18.31	13.79	18.01	18.15	19.28	15.52	25.26	19.26	0	7.46	4.43	1.55	76.55
E50 1-4-6	6.04	8.92	2.95	12.55	7.43	10.7	13.55	14.21	8.24	1.24	2.95	3.54	0	66.85
E50 1-4-7	5.57	12.14	6.31	11.68	0.1	14.04	5.06	11.99	7.05	0.23	0.21	3.48	0	58.9
E50 1-4-8	1.51	8.86	5.58	8	3.25	9.92	6.72	10.13	2.84	0.8	2.45	1.01	0	51.55

Table C.1 SSQR obj. function deviations from UB for 50-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E50 1-4-9	6.71	13.87	11.23	9.59	10.69	15.88	12.86	12.31	9.89	5.53	2.83	0	7.26	70.82
E50 1-4-10	6.62	7.98	13.32	13.76	10.31	13.12	10.82	14.77	6.87	3.02	6.55	7.36	0	89.09
AVERAGE	**5.77**	**11.69**	**10.85**	**12.9**	**8.8**	**12.93**	**11.3**	**14.5**	**9**	**1.93**	**4.32**	**2.95**	**2.72**	**67.09**
E50 5-1-1	14.19	2.44	2.24	4.55	0	2.22	2.61	5.69	2.91	10.09	12.71	9.27	10.54	23.48
E50 5-1-2	13.95	0	1.75	3.23	1.55	2.89	1.48	1.85	0.24	13.08	11.14	10.2	10.87	24.09
E50 5-1-3	14.07	3.69	1.35	2.29	0	4.44	3.88	5.26	1.13	11.82	12.02	12.9	12.69	34.05
E50 5-1-4	15.27	0.31	3.85	3.71	0	3.68	0.54	2.79	0	12.46	11.13	13.7	11.98	36.64
E50 5-1-5	16.01	0.86	1.46	2.42	0.41	2.94	0	4.15	2.29	15.81	14.09	14.1	10.2	37.97
E50 5-1-6	15.64	3.66	0.76	4.41	1.22	0.99	2.21	5.86	0	11.82	12.94	9.76	11.83	30.97
E50 5-1-7	19.96	5.46	5.69	7.21	0.04	3.18	6.65	5.73	0	15.91	12.67	13.6	15.27	41.77
E50 5-1-8	12.73	1.24	3.22	3.86	0	2.57	1.24	4.05	1.54	9.21	13.48	9.07	22.69	28.35
E50 5-1-9	15.72	1.63	2.39	3.23	0.91	1.05	0	3.27	2.82	10.43	11.69	8.43	8.17	23.67
E50 5-1-10	13.57	0.83	0	1.69	0.05	0.78	0.8	1.7	1.15	9.4	12.96	10.7	10.02	26.5
E50 5-2-1	14.49	2.3	3.17	0	2.38	3.23	1.69	4.17	3.67	10.98	14.92	10.4	14.45	23.65
E50 5-2-2	11.23	2.57	1.39	3.87	0	1.7	1.76	4.9	0.6	10.77	12.59	9.19	10.75	23.74
E50 5-2-3	14.97	2.23	0	3.16	1.07	1.64	3.19	3.49	0.44	11.17	10.46	10.5	11.86	40.46
E50 5-2-4	16.87	3.75	0.75	7.25	0.54	2.84	6.07	7.55	0	12.32	17.18	15.5	17.13	39.04
E50 5-2-5	17.47	0	1.59	4.49	0.17	0.97	1.01	2.54	2.19	16.19	15.6	11.4	15.1	44.3
E50 5-2-6	11.85	1.14	0	0.99	0.48	0.59	0.04	3.65	0.94	11.68	15.32	11.6	11.77	31.26
E50 5-2-7	14.12	1.13	2.93	2.78	0	2.2	0.85	2.95	0.2	12.23	11.52	13.1	9.69	23.37
E50 5-2-8	14.65	2.24	0.82	1.79	0	4.22	0.07	2.17	0	13.18	16.95	15.1	14.47	31.21
E50 5-2-9	11.42	0.79	2.6	3.1	0	1.16	1.13	1.53	0.68	10.73	10.96	9.42	8.66	21.98
E50 5-2-10	13.87	1.4	1.84	2.95	0.06	1.83	0.91	2.96	0	11.64	10.53	9.54	9.56	14.72
E50 5-3-1	11.63	0.54	0.74	1.62	0.34	0.03	0	1.9	0	9.78	9.16	11	10.06	47.49
E50 5-3-2	13.9	1.75	0	0.82	1.38	4.99	1.25	3	2.38	12.71	12.92	12.6	10.92	26
E50 5-3-3	18.46	0	1.1	2.74	3.4	7.25	3.07	3.3	5.03	14.86	18.39	14.7	11.99	25.5
E50 5-3-4	17.96	8.05	1.49	5.97	0	6.16	2.43	6.83	1.11	17.78	15.97	14.2	14.61	30.83
E50 5-3-5	13.04	0.63	0.42	1.01	0	2.26	0.54	2.5	0.52	11.32	12.99	13.4	14.81	40.81
E50 5-3-6	17.07	0	2.11	4.34	2.82	3.41	0.67	3.96	2.73	11.98	14.94	13.8	13.16	26.65
E50 5-3-7	12.85	1.03	1.52	2.37	0	1.77	0.49	3.21	0.49	9.42	13.55	12.2	11.19	26.97
E50 5-3-8	19.45	0	1.18	1.67	3.12	1.52	0.64	4.73	2.83	13.07	18.08	15.8	13.59	44.88
E50 5-3-9	16.84	3.04	0	1.63	0.61	5.15	1.57	2.65	0.31	12.13	13.71	12.6	13.3	25.16
E50 5-3-10	18.6	3.19	0.11	2.87	0	3.41	2.32	2.27	1.91	14.39	14.38	12.7	13.28	30.93
E50 5-4-1	16.37	1.72	2.75	3.15	0	3.48	2.94	3.04	0.09	16.75	13.82	15.7	15.32	30.22
E50 5-4-2	14.3	2.71	1.38	4.3	0.61	4.14	2.94	3.33	0	13.72	13.66	12.6	13.49	21.35
E50 5-4-3	13.75	0	3.39	5.12	2.19	3.2	1.78	3.35	2.27	12.12	11.82	11.2	13.95	40.18
E50 5-4-4	15.12	3.98	0	3.82	1.35	3.07	1.58	2.87	1.67	13.86	15.81	13	14.31	40.38
E50 5-4-5	19.41	0.87	0	0.05	0.83	2.28	3.37	5.65	1.28	12.51	12.2	14.2	11.8	26.84
E50 5-4-6	13.67	1.55	0	0.9	0.03	3.34	3.34	3.12	0.71	13.42	14.06	14.3	14.4	23
E50 5-4-7	16.36	1.2	1.06	0.4	0	1.89	0.15	3.57	0	13.33	14.56	17.5	14.45	24.32
E50 5-4-8	13.86	0.19	0.08	2.74	0	0.07	0.08	0.72	0.22	10.4	13.7	11.7	12.6	34.87
E50 5-4-9	20.94	3.13	2.03	6.77	2.7	6.03	1.13	7.42	0	15.69	17.57	15.5	19.01	28.2
E50 5-4-10	18.59	3.72	6.87	7.02	0	3.17	1.86	8.66	3.55	15.16	18.34	17.1	14.7	44.02
AVERAGE	**15.36**	**1.87**	**1.6**	**3.16**	**0.71**	**2.79**	**1.71**	**3.81**	**1.2**	**12.63**	**13.76**	**12.6**	**12.97**	**30.99**
E50 10-1-1	16.99	0.27	0.61	0.61	0	0.61	0.94	0.61	0.61	15.19	15.94	14.1	15.68	3.57
E50 10-1-2	27.32	0	10.43	10.19	8.5	8.84	8.84	8.58	8.84	24.79	25.7	22	25.75	12.24
E50 10-1-3	21.63	1.02	0	1.48	0	1.02	1.02	3.75	1.02	12.35	17.73	14.3	15.84	3.65

Table C.1 SSQR obj. function deviations from UB for 50-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E50 10-1-4	16.17	0	0.74	0.96	0.48	0.05	0	0.62	0.36	2.68	23.82	9.61	11.5	0.56
E50 10-1-5	22.46	0.14	1.02	3.71	0	1.28	1.53	3.05	0.14	11.51	17.2	12.9	10.61	13.43
E50 10-1-6	21.15	0	0	0.35	0	0	0	0	0	10.02	17.52	12	10.68	3.17
E50 10-1-7	20.42	2.19	1.78	0.23	0	0	2.19	0.23	0	8.67	16.69	12.8	10.65	1.01
E50 10-1-8	13.03	0	0	0.17	0	0	0	0.17	0	10.17	12.6	10.4	9.25	0.37
E50 10-1-9	15.35	1.92	0	2.17	0	0.13	1.92	0.6	0.13	8.39	12.94	8.42	9.27	2
E50 10-1-10	20.6	3.15	0	2.86	3.15	3.15	3.15	2.86	0.28	11.94	18.78	14.6	11.55	5.38
E50 10-2-1	17.87	0.18	0	0.18	0	0	0	0.18	0	11.78	14.14	12.4	11.59	0.2
E50 10-2-2	21.18	1.7	0	0	0.99	1.7	2	0.69	1.01	12.26	17.4	14	11.57	10.99
E50 10-2-3	18.45	0	0	0	0	0	0	0	0	11.37	13.96	12	10.85	0.33
E50 10-2-4	16.39	0	0	0.43	0	0	0	0	0	12.46	16.08	11.5	11.46	0
E50 10-2-5	25.46	9.83	9.83	9.83	9.83	9.83	9.83	9.83	0	22.7	23.4	21.6	19.65	11.56
E50 10-2-6	16.67	0.16	0.22	0.37	0	0	0.16	0.22	0	10.28	13.02	11.7	11.31	1.23
E50 10-2-7	16.78	0.11	0	0.24	0	0.11	0.11	0.11	0	8.94	12.68	12	10.95	2.04
E50 10-2-8	16.05	0	0	0.82	0	0	0	0	0	9.47	12.5	9.4	9.55	6.39
E50 10-2-9	15.11	0	0	0	0	0	0	1.95	0	9.94	12.74	12	11.24	0
E50 10-2-10	17.49	0	0	4.46	0	0	0	1.92	0	10.46	15.01	12.8	11.94	0
E50 10-3-1	16.3	0.2	0.5	0	0	0.2	0	0	0	11.05	13.77	16.2	10.18	2.13
E50 10-3-2	15.64	0	0.59	1.38	0.84	0	0	0.84	0	14.94	15.23	13.8	13.57	6.1
E50 10-3-3	15.11	0	0	0	0	0	0	0	0	13.12	14.28	13.4	13.31	0
E50 10-3-4	14.95	0	0.22	0.4	0	0.22	0.19	0	0	11.46	11.66	12.5	12.11	0.48
E50 10-3-5	17.22	0	1.33	1.33	0.94	0	0	0.45	0	14.53	15.68	14.5	15.46	7.23
E50 10-3-6	16.09	0	0	0	0	1.11	0	1.11	0	12.86	13.59	13.3	12.82	3.46
E50 10-3-7	16.98	0.14	0	0.06	0	0.14	0.14	0.14	0	14.88	13.63	13.1	14.77	17.85
E50 10-3-8	14.98	0	1.03	0	0	0	0	0	0	13.81	14.85	12.9	14.09	6.17
E50 10-3-9	29.65	11.07	11	11.07	11	0	11.07	11.07	11	26.51	26.97	26.3	26.19	13.5
E50 10-3-10	17.72	0	2.38	1.07	0	0	0	0	0	15.02	15.28	12.9	14.93	1.1
E50 10-4-1	16.72	0	0	0	0	0.83	0	0.5	0	15.36	13.05	14.8	15.07	1.8
E50 10-4-2	15.01	0	0	0	0	0	0	0	0	13.2	12.97	12	9.07	0
E50 10-4-3	16.04	0	0	0	0	0	0	2.78	0	11.92	13.57	13	11.97	0
E50 10-4-4	16.53	0	0	0	0	0	0	0	0	12.32	13.66	12.5	13.41	0.29
E50 10-4-5	21.11	0	0	0.9	0.96	1.4	1.3	1.02	1.39	14.49	17.71	16.7	14.55	10.8
E50 10-4-6	15.65	0	0	0	0	0	0	0	0	9.71	13.28	11.6	11.09	0
E50 10-4-7	15.56	0.83	0	0.91	0.83	0.83	0.83	0.91	0.83	11.08	13.58	12.9	12.08	3.6
E50 10-4-8	18.17	0	1.19	1.6	0	0.41	0	1.19	0	16.99	15.42	12.8	15.05	5.59
E50 10-4-9	13.84	0	0	0	0	0	0	0	0	11.81	12.72	12.6	10.57	0
E50 10-4-10	18.25	0.73	0.13	0.73	0.73	0.73	0.73	0	0.73	12.27	15.14	12.6	13.31	3.17
AVERAGE	**17.95**	**0.85**	**1.07**	**1.46**	**0.95**	**0.81**	**1.15**	**1.38**	**0.65**	**12.82**	**15.65**	**13.5**	**13.11**	**4.03**
E50 15-1-1	17.04	0	0	0	0	0	0	0	0	11.08	14.33	10.3	9.22	0
E50 15-1-2	18.14	0	0	0	0	0	0	0	0	11.12	15.78	11.8	12.32	0
E50 15-1-3	17.98	0	0	0	0	0	0	0	0	10.74	14.04	12.8	9.74	0
E50 15-1-4	16.53	0	0	0	0	0	0	0	0	10.05	14.64	11.8	10.36	0
E50 15-1-5	14.35	0	0	0	0	0	0	0	0	9.14	13.59	9.71	8.5	0
E50 15-1-6	20.01	0	0.47	3.02	0	0	0	4.35	0	10.42	16.9	11.6	9.85	0
E50 15-1-7	15.65	0	0	0.41	0	0	0	0	0	9.11	13.93	10.5	8.81	0
E50 15-1-8	16.7	0	0	0	0	0	0	0	0	8.3	14.84	10.6	7.97	0
E50 15-1-9	17.03	0	0	1.95	0	0	0	0	0	9.71	13.54	11	9.65	0
E50 15-1-10	18.89	0	0	0	0	0	0	0	0	11.54	14.16	12.7	11.51	0

Table C.1 SSQR obj. function deviations from UB for 50-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E50 15-2-1	16.41	0	0	0	0	0	0	0	0	11.38	15.46	13.1	12.53	0
E50 15-2-2	19.37	1.54	0	1.54	1.54	1.54	1.54	1.54	1.54	11.54	15.96	14.6	13.67	1.54
E50 15-2-3	19.2	0	0	0.71	0	0	0	0	0	12.97	16.96	13.4	14.79	0
E50 15-2-4	17.27	0	0	0	0	0	0	0	0	13.63	15.46	12.9	11.69	0
E50 15-2-5	16.32	0	0	0	0	0	0	0	0	11.25	15.78	11.5	13.83	0
E50 15-2-6	16.92	0	0	0	0	0	0	0	0	11.34	16.01	13.1	10.47	0
E50 15-2-7	19.57	0	0	0	0	0	0	0	0	11.98	18.22	13	12.81	0
E50 15-2-8	21.2	0	0	0	0	0	0	0	0	14	17.05	15.3	12.99	0
E50 15-2-9	19.18	0	0	0.2	0	0	0.2	0.2	0	13.04	16.68	14.6	11.06	0
E50 15-2-10	19.02	0	0	0	0	0	0	0	0	11.24	15.62	13.3	10.44	0
E50 15-3-1	14.23	0	0.37	0.37	0	0	0	0.37	0	11.48	13.57	10.4	11.16	0
E50 15-3-2	16.92	0	0	0	0	0	0	0	0	11.53	12.99	13.8	11.15	0
E50 15-3-3	18.92	0	0	0	0	0	0	0	0	15.7	16.29	16	17.8	0
E50 15-3-4	16.24	0	0	0	0	0	0	0	0	12.55	12.98	12.6	12.29	0
E50 15-3-5	18.82	0	0	0	0	0	0	0	0	16.39	16.99	16.2	15.23	0
E50 15-3-6	15.73	0	0	0	0	0	0	0	0	14.85	15.52	15.2	14.49	0
E50 15-3-7	17.12	0	0	0.56	0	0	0	0	0	17.02	15.88	14.9	17.02	0
E50 15-3-8	14.21	0	0	0	0	0	0	0	0	12.32	13.67	11.9	13.22	0
E50 15-3-9	15.59	0	0	0	0	0	0	0	0	13.71	15.26	12.8	12.83	0
E50 15-3-10	17.35	0	0.64	0	0	0	0	0	0	15.26	15.45	15.8	15.22	0
E50 15-4-1	16.65	0	0	0	0	0	0	0	0	13.63	16.6	12.4	13.68	0
E50 15-4-2	18.28	0	0	0	0	0	0	0	0	13.62	14.86	14.8	13.55	0
E50 15-4-3	17.45	0	0	0	0	0	0	0	0	14.8	15.5	14.3	15.67	0
E50 15-4-4	17.39	0	0	0	0	0	0	0	0	16.49	15.29	15.3	15.19	0
E50 15-4-5	18.18	0	0	0	0	0	0	0	0	14.5	15.51	14.3	15.51	0
E50 15-4-6	16.15	0	0	0	0	0	0	0	0	9.53	13.54	11.2	10.89	0
E50 15-4-7	14.41	0	0	0	0	0	0	0	0	10.92	13.08	11.7	11.28	0
E50 15-4-8	14.93	0	0	0	0	0	0	0	0	10.79	13.71	11	10.97	0
E50 15-4-9	16.59	0	0	0	0	0	0	0	0	11.3	15.5	13.7	11.06	0
E50 15-4-10	17.24	0	0	0	0	0	0	0	0	11.71	14.16	10.9	12.02	0
AVERAGE	**17.23**	**0.04**	**0.04**	**0.22**	**0.04**	**0.04**	**0.04**	**0.16**	**0.04**	**12.29**	**15.13**	**12.9**	**12.31**	**0.04**

Table C.2 SSQR obj. function deviations from UB for 100-activity instances

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E100-1-1-1	7.5	11.51	0.31	8.94	0	7.34	1.97	11.25	0	2.74	2.31	4.6	2.78	89.47
E100-1-1-2	1.6	3.06	0.78	2.93	0.54	1.21	2.09	4.2	0	1.2	1.45	0	1.36	35.01
E100-1-1-3	5.34	6.24	3.88	6.8	1.29	5.01	6.89	7.02	1.29	2.59	2.42	0	2.27	35.85
E100-1-1-4	5.7	7.31	1.42	7.55	0	5.38	2.47	9.66	0	1.93	3	1.46	1.98	48.48
E100-1-1-5	6.15	8.56	4.01	8.44	2.87	5.94	7.14	9.7	2.87	3.38	4.66	0	3.38	43.66
E100-1-1-6	1.71	5.91	0	4.28	0.28	2	2.84	7.32	0.28	3.79	2.91	0.6	0.7	73.1
E100-1-1-7	7.71	8.64	1.98	8.9	1.98	1.98	5.85	9.67	1.98	1.03	2.16	0	2.25	6.5
E100-1-1-8	6.55	4.31	3.97	5.84	1.72	4	0.64	6.89	1.72	0	0.9	0.98	0.05	28.45
E100-1-1-9	6.91	5.97	2.26	4.42	1.08	4.43	3.99	6.86	1.08	1.88	2.78	0	1.63	30.62
E100-1-1-10	5.74	5.18	2.74	5.68	1.45	4	3.55	7.9	1.45	2.83	3.45	0	2.19	18.21
E100-1-2-1	3.04	8.5	4.38	2.97	3.5	6.96	2.97	6.32	3.13	0	5.56	2.79	0.45	66.31
E100-1-2-2	2.7	4.75	1.78	2.11	1.38	4	5.02	6.62	1.23	0	3.27	2.27	0.79	68.97
E100-1-2-3	5.86	6.74	1.53	6.9	0.57	2.05	4.9	9.31	0.43	0.17	1.24	0	1.19	72.62
E100-1-2-4	5.95	11.91	6.78	12.32	4.67	7.81	11.23	10.54	4.67	0	2.77	2.14	1.78	82.65
E100-1-2-5	6.84	6.52	1.91	3.89	1.35	7.46	7.93	7.63	1.71	0.71	3.28	0	1.48	84.89
E100-1-2-6	3.23	7.92	2.43	7.43	1.96	5.61	6.73	8.23	1.96	0.09	5.14	0	0.91	79.66
E100-1-2-7	9.56	8.25	2.77	5.4	11.66	5.5	3.26	11.97	5.27	3.64	6.84	0	4.6	61.19
E100-1-2-8	5.69	5.07	3.15	1.44	3.65	5.51	4.6	7.08	1.44	0	4.3	0.65	0.23	66.86
E100-1-2-9	9.22	10.15	3.31	2.68	11.96	5.1	4.63	13.16	2.92	7.21	8.97	0	6.38	60.43
E100-1-2-10	5.93	7.88	3.98	4.59	6.6	6.54	5.32	9.75	4.57	0.49	1.99	0.24	0	75.58
E100-1-3-1	2.19	7.59	4.5	3.41	4.53	10.38	4.91	9.2	2.08	0	1.08	0.86	0.17	52.95
E100-1-3-2	5.85	14.24	8.19	9.04	10.95	15.58	9.02	16.33	8.02	4.92	2.52	0	1.94	70.85
E100-1-3-3	8.23	8.73	7.56	6	7.11	10.38	6.39	11.04	5.01	0.21	3.15	5.21	0	79.02
E100-1-3-4	6.74	7.1	4.29	1.78	2.5	9.06	1.11	9.72	1.85	0.53	3.3	0	0.22	70.08
E100-1-3-5	5.52	10.15	4.9	5.49	4.78	6.23	7.64	12.47	4.17	0	1.41	3.8	0.59	71.92
E100-1-3-6	6.7	12.06	7.79	6.15	14.16	13.64	11.19	11.41	5.65	0	5.6	2.34	1.83	80.83
E100-1-3-7	3.13	8.29	4.15	1.42	5.15	8.49	3.04	10.47	2.46	0.73	5.11	4.94	0	72.58
E100-1-3-8	5.83	11.36	4.61	3.88	8.16	9.31	3.31	12.18	3.89	0	3.2	0.88	2.36	52.85
E100-1-3-9	7.88	13.76	6.61	5.68	12.55	10.02	12.3	14.03	5.31	0	4.76	1.59	5.08	66.77
E100-1-3-10	11.17	14.46	10.17	5.68	12.6	12.47	6.06	15.59	5.31	3.24	2.72	4.98	0	78.32
E100-1-4-1	6.64	12.38	8.99	9.65	9.5	10.68	10.87	14.34	10.25	0	3.97	1.21	0.07	79.06
E100-1-4-2	6.24	18.43	16.5	13.14	16.28	18.64	14.09	20.26	11.19	0	4.88	3.03	5.37	75.77
E100-1-4-3	3.93	10.29	7.81	9.63	9.02	11.39	5.58	14.62	6.57	0	4.33	1.06	0	86.1
E100-1-4-4	7.46	14.46	12.19	7.64	12.86	14.81	10.81	14.86	8.1	1.33	4.6	3.16	0	77.57
E100-1-4-5	6.01	15.05	13.04	12.02	14.53	16.86	9.21	16.77	10.94	2.14	0	1.88	1.9	76.47
E100-1-4-6	5.06	16.26	13.91	10.48	11.55	17.88	15.91	19.28	11.84	1	5.75	2.66	0	66.07
E100-1-4-7	6.41	18.04	16.8	15.01	18.15	19.02	15.63	17.36	12.16	1.37	8.61	6.66	0	66.68
E100-1-4-8	2.53	10.74	11.69	7.19	17.37	14.01	12.04	17.4	7.95	3.18	2.82	0	1.46	55.18
E100-1-4-9	6.25	13.67	8.08	9.86	11.38	16.58	8.37	15.97	8.57	1.73	4.24	4.44	0	72.77
E100-1-4-10	4.38	16.94	12.85	12.53	14.66	17.39	11.07	20.2	12.52	2.06	6.57	2.48	0	76.84
AVERAGE	**5.78**	**9.96**	**5.95**	**6.73**	**6.91**	**9.02**	**6.81**	**11.62**	**4.55**	**1.4**	**3.7**	**1.68**	**1.43**	**63.93**
E100-5-1-1	32.27	24.1	22.24	23.33	22.24	22.18	23.72	24.26	22.24	19.75	16.49	0	22.52	70.99
E100-5-1-2	6.14	0	0	0	0	0	0	0	0	4.62	4.62	4.04	4.58	44.77
E100-5-1-3	6.24	2.09	0.07	0.98	0	0.28	0.29	2.04	0	6.27	4.98	3.42	6.25	34.02
E100-5-1-4	6.09	5.42	0	4.97	0	0.3	1.25	3.01	0	7.4	5.19	2.72	7.48	35.29
E100-5-1-5	11.64	5.81	4.05	6.94	3.08	3.01	5.37	9.07	3.08	12.01	7.26	0	12.71	53.34
E100-5-1-6	4.82	1.1	0.27	2	0	0.25	0.88	2.77	0	6.66	6.58	4.42	6.71	48.04
E100-5-1-7	18.06	11.34	10.49	13.51	10.49	11.11	12.62	13.58	10.49	17.88	16.67	0	14.5	45.59

Table C.2 SSQR obj. function deviations from UB for 100-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E100-5-1-8	25.84	22.26	18.73	22.5	18.53	19.2	21.08	23.81	18.53	17.32	20.49	0	19.86	57.75
E100-5-1-9	4.21	0.45	0.51	0.09	0.51	0	0.55	0.14	0.51	5.71	6.16	3.62	7.88	36.23
E100-5-1-10	6.75	1.27	0.06	0.97	0	1.39	0.44	1.27	0.06	4.69	5.07	4.1	6.32	40.48
E100-5-2-1	11.33	1.1	0	1.58	0	0.7	0.29	0.93	0	11.46	9.94	7.62	11.66	33.99
E100-5-2-2	13.3	2.51	0	2.8	0	1.12	1.69	2.77	0	10.29	11.2	8.23	11.75	50.58
E100-5-2-3	11.26	1.86	0.7	1.28	0	0	0.67	1.63	0	12	10.27	6.36	10.88	26.94
E100-5-2-4	10.49	2.08	0.33	1.01	0	0.08	1.73	1.4	0	11.05	8.49	6.77	11.07	42.56
E100-5-2-5	11.99	3.04	0.27	2.31	0	0.74	2.74	2.55	0	10.54	7.98	7.07	8.85	37.2
E100-5-2-6	8.72	1	0	2.95	0	0.22	1.03	1.02	0	8.84	7.09	5.46	6.93	33.32
E100-5-2-7	9.31	2.33	0.7	0	0.97	0.69	1.37	1.63	0.97	9.3	8.18	6.38	10.39	35.76
E100-5-2-8	13.13	3.2	0.02	1.42	0	0.24	1.11	2.05	0	10.37	10.32	8.05	13.17	40.5
E100-5-2-9	9.19	0.71	0.16	0.73	0	0.39	0.16	1.11	0.16	8.15	9.02	5.67	9.44	30.9
E100-5-2-10	7.68	1.95	0.09	1.49	0	1.69	0.72	1.67	0	7.72	6.9	5.86	9.35	27.17
E100-5-3-1	17.08	3.2	1.08	0.39	0.27	2.37	0.12	4.16	0	10.58	14.06	11.2	12.72	28.46
E100-5-3-2	11.33	2.26	1.67	2.42	0.56	0.81	4.06	1.05	0	7.23	8.45	7.64	7.74	35.66
E100-5-3-3	14.53	2.09	0	1.31	1.6	1.71	1.2	1.5	1.38	11.15	9.57	9.05	10.21	45.78
E100-5-3-4	14.1	1.72	0.03	3.49	0	2.64	5.58	1.77	0	12.57	10.62	9.24	10.64	37.21
E100-5-3-5	12.96	3.02	0.51	2.66	0	2.31	0.93	3.56	0	11.34	10.32	9.43	11.7	42.11
E100-5-3-6	15.76	2.02	0	1.65	3.09	2.18	1.64	1.67	1.52	10.03	10.06	11.4	10.51	34.76
E100-5-3-7	14.25	0.06	1.4	1.77	0	1.99	0.11	2.26	0.37	11.47	12.16	12.2	11.79	41.65
E100-5-3-8	15.2	1.48	1.48	2.6	0.05	1.59	0.54	4.02	0	12.42	11.79	9.97	12.28	34.32
E100-5-3-9	13.1	2.93	0.92	2.71	0.42	1.69	0.81	3.26	0	13.03	12.14	9.74	12.75	40.27
E100-5-3-10	18.87	4.01	2.72	2.01	0.95	3.04	0	5.32	0.63	13.62	15.34	12.4	14.55	41.19
E100-5-4-1	14.86	2.19	2	2.75	0	3.4	1.32	2.12	1.4	11	14.24	12	10.5	34.58
E100-5-4-2	12.86	1.24	1.28	3.75	0.04	2.33	0	1.07	0.63	7.95	11.52	13	13.13	45.72
E100-5-4-3	14.94	3.64	2.41	2.86	0	2.78	1.13	2.91	0.36	12.32	12.55	10.2	11.05	39.46
E100-5-4-4	12.92	0.54	0.74	1.22	0.02	1.73	0.28	1.4	0	12.93	13.12	12.9	12.22	33.21
E100-5-4-5	13.75	1.2	1.74	1.11	0.35	1.81	1.54	3.63	0	11.5	10.33	10.4	10.63	49.89
E100-5-4-6	17.52	2	2.32	2.35	0	2.73	2.61	5.36	1.64	13	13.69	12.8	14.55	35.46
E100-5-4-7	15.47	1.2	2.94	1.47	1.03	3.03	0.03	6.49	0	10.93	12.57	12.2	11.49	45.98
E100-5-4-8	16.84	2.66	1.4	4.03	0.44	2.15	0	4.08	1.3	14.29	12.72	12.8	14.7	59.14
E100-5-4-9	14.19	3.08	0.17	1.59	1.91	2.44	0.33	3.64	0	9.04	12.29	12.1	13.71	24.87
E100-5-4-10	13.61	3.69	1.92	3.84	0.54	4.1	2.82	4.24	0	13.11	12.3	12.5	11.97	45.04
AVERAGE	**13.07**	**3.45**	**2.14**	**3.42**	**1.68**	**2.76**	**2.57**	**4.01**	**1.63**	**10.79**	**10.57**	**7.82**	**11.28**	**40.5**
E100-10-1-1	10.25	3.14	1.06	4.31	0	0.42	0.09	3.88	0	6.86	6.17	4.87	7.58	17.23
E100-10-1-2	6.58	1.45	0	1.23	0	0	0	1.23	0	5.89	5.22	3.19	6.15	1.98
E100-10-1-3	31.01	23.45	23.86	23.86	23.45	23.45	23.45	23.86	23.45	30.08	29.77	0	30.28	26.01
E100-10-1-4	7.42	0	0	0	0	0	0	0	0	7.27	8.65	4.53	8.8	4.68
E100-10-1-5	7.73	3.11	0	7.56	0	0.25	0.34	5.48	0	10.68	9.6	6.18	10.55	11.81
E100-10-1-6	8.19	2.46	0	4.07	0	0	1.35	3.78	0	8.91	8.02	6.62	8.92	10.79
E100-10-1-7	9.61	2.25	2.25	6.18	2.25	2.25	4.05	2.8	2.25	6.55	6.6	6.03	6.03	0
E100-10-1-8	6.48	0.56	0	0	0.56	0.56	0.56	0	0.56	4.86	2.33	2.5	3.23	5.13
E100-10-1-9	8.49	0.3	0	1.84	0	0.6	0.56	1.84	0	10.12	8.51	7.3	8.69	11.08
E100-10-1-10	9.4	0.13	1.27	4.07	0	0	0	4.03	0	7.77	5.9	4.65	8.06	14.82
E100-10-2-1	10.49	0.21	0.35	0.56	0	0	0.21	0.56	0	7.54	8.09	9.52	8.97	6.46
E100-10-2-2	9.75	0.24	0	0	0	0	0	0.24	0	9.6	8.53	6.18	9.88	5.82
E100-10-2-3	7.61	0.07	0	0.72	0	0	0.07	0.72	0	10.02	8.37	4.5	9.71	1.34
E100-10-2-4	10.28	0	0	0.9	0	0	0	0	0	6.43	6.06	6.43	7.04	4.89

Table C.2 SSQR obj. function deviations from UB for 100-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E100-10-2-5	9.38	0	0	0	0	0	0	0	0	3.4	5.83	2.98	7.1	1.77
E100-10-2-6	10.28	0.16	0	0.04	0	0.12	0.16	0.16	0	11.46	11.89	8.95	12.9	8.43
E100-10-2-7	9.49	0	0	0	0	0	0	0	0	10.35	10.28	10.4	11.08	7.27
E100-10-2-8	11.47	0	0	0.73	0	0	0	0.73	0	8.66	6.99	5.68	9.48	2.82
E100-10-2-9	10.67	0	0	0	0	0	0.09	0	0	11.18	11.51	9.62	12.22	2.46
E100-10-2-10	10.07	1.13	0	1.22	0	0	1.13	1.22	0	10.85	11.26	7.86	11.39	0.82
E100-10-3-1	13.61	0.2	0	0	0	0	0	0.84	0	13.62	14.55	10.8	14.73	8.41
E100-10-3-2	14.52	0.08	0	1.07	0	0	0	0.59	0	10.87	10.82	9.03	11.18	6.21
E100-10-3-3	10.7	0	0	0	0	0	0	0	0	9.22	12.14	8.47	12.28	3.46
E100-10-3-4	13.43	0.26	0	0	0	0.26	0	0.93	0	13.11	13.06	18.5	13.37	5.84
E100-10-3-5	15.78	0.25	0.07	3.75	0	0.18	0	0.25	0	15.57	15.83	14.6	16.24	1.25
E100-10-3-6	14.8	0	0	0	0	0	0	0	0	9.09	10.71	6.39	8.02	3.94
E100-10-3-7	16.13	0	0.33	0	0	0.33	0	0	0	15.13	15.2	13.1	16.05	6.61
E100-10-3-8	12.13	0.1	0	0	0	0.1	0	0.1	0	8.11	9.95	6.5	9.51	3.99
E100-10-3-9	11.47	0	0	0	0	0	0	0	0	11.91	13.12	10.6	11.99	7.16
E100-10-3-10	11.96	0.16	0	1.39	0	0	0	0	0	11.31	13.04	10.5	12	1.49
E100-10-4-1	18.61	0.66	0.93	0.31	0	0.93	1.08	0.93	0	12.84	16.12	13.2	12.2	5.93
E100-10-4-2	15.65	0.61	0.51	0.51	0.51	0.51	0.51	0.61	0.51	8.32	7.99	7.96	8.12	0
E100-10-4-3	19.13	0	0.72	0.63	0	0	0.38	0.38	0	17.31	20.16	19.9	19.06	13.03
E100-10-4-4	16.88	1.19	0.72	0.72	0.05	0	0.05	1.19	0.05	14.59	15.29	14.6	15	14.37
E100-10-4-5	16.04	0.65	0.76	0.65	0.65	0.65	0.65	0.65	0.65	11.84	12.77	11.3	11.65	0
E100-10-4-6	16.52	0.19	0	0.11	0.19	0.34	0.07	0.56	0.13	16.34	16.43	15.4	16.51	2.98
E100-10-4-7	15.13	0.43	0	0	0	0.43	0	0.43	0	7.81	8.42	5.3	7.94	4.13
E100-10-4-8	18.73	2.18	0	0.83	0	1.83	0.48	2.18	0.49	12.92	16.35	14.8	13.99	6.43
E100-10-4-9	19.09	1.08	0.22	0	0.22	1.3	1.08	1.08	0.22	10.49	11.44	10.5	9.42	3.24
E100-10-4-10	15.49	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	13.08	14.85	13.5	12.11	0
AVERAGE	**12.76**	**1.18**	**0.84**	**1.7**	**0.71**	**0.88**	**0.92**	**1.55**	**0.72**	**10.8**	**11.2**	**8.82**	**11.24**	**6.1**
E100-15-1-1	38.61	27.31	27.11	32.73	27.11	27.11	29.04	29.04	27.11	15.26	19.99	0	19.93	31.5
E100-15-1-2	23.55	19	15	19.04	15	15	15	19.26	15	10.65	7.64	0	9.87	16.56
E100-15-1-3	20.38	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	8.95	10.25	0	11.18	14.03
E100-15-1-4	21.02	13.27	15.74	22.37	13.27	13.27	18.91	15.92	13.27	10.46	7.84	0	10.82	12.24
E100-15-1-5	24.32	17.59	15.91	21.05	15.91	15.91	17.59	21.05	15.91	11.25	8.77	0	15.81	17.37
E100-15-1-6	23.36	14.88	16.11	16.11	14.88	14.88	14.88	16.11	14.88	15.32	11.32	0	14.33	17.65
E100-15-1-7	25.26	16.39	16.39	19.52	16.39	16.39	17.01	19.52	16.39	15.28	11.88	0	7.87	16.43
E100-15-1-8	19.83	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	10.99	11.73	0	13.21	11.85
E100-15-1-9	29.44	21.04	21.04	22.07	21.04	21.04	21.04	21.04	21.04	5.09	5.12	0	4.82	21.87
E100-15-1-10	23.29	14.32	14.32	15.3	14.32	14.32	15.3	15.3	14.32	4.57	4.2	0	6.88	13.78
E100-15-2-1	60.42	43.81	43.81	43.81	43.81	43.81	43.81	43.81	43.81	17.04	16.34	0	15.07	43.96
E100-15-2-2	63.71	47.76	47.76	47.76	47.76	47.76	47.76	47.76	47.76	18.78	16.44	0	17.65	51.67
E100-15-2-3	56.65	40.25	40.25	40.25	40.25	40.25	40.25	40.25	40.25	7.53	3.36	0	5.71	41.56
E100-15-2-4	81.55	62.91	62.91	66.51	62.91	62.91	62.91	66.51	62.91	17.3	15.77	0	18.23	63.52
E100-15-2-5	55.34	41.38	41.38	41.38	41.38	41.38	41.38	41.38	41.38	12.28	10.22	0	12.54	40.97
E100-15-2-6	76.93	60.69	60.69	61.56	60.69	60.69	60.69	61.56	60.69	19.22	18.82	0	22.08	59.21
E100-15-2-7	75.89	56.14	56.14	58.39	56.14	56.14	56.14	58.39	56.14	24.83	18.35	0	22.2	56.55
E100-15-2-8	73.83	56.85	56.85	56.85	56.85	56.85	56.85	56.85	56.85	11.89	11.96	0	12.07	57.54
E100-15-2-9	78.05	59.54	61.41	59.81	59.54	59.54	59.54	59.54	59.54	23.2	14.38	0	23.61	58.89
E100-15-2-10	69.14	53.32	53.32	53.32	53.32	53.32	53.32	53.32	53.32	15.34	17.29	0	18.84	55.53
E100-15-3-1	174.26	140.2	140.24	140.2	140.24	140.2	140.24	140.2	140.24	28.96	29.27	0	27.13	145.1

Table C.2 SSQR obj. function deviations from UB for 100-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E100-15-3-2	136.77	104.9	104.93	104.9	104.93	104.9	104.93	104.9	104.93	19.19	20.39	0	18.94	103.3
E100-15-3-3	143.06	111.2	111.17	111.2	111.17	111.2	111.17	111.2	111.17	13.9	23.66	0	15.52	119.6
E100-15-3-4	132.57	103.3	103.25	103.3	103.25	103.3	103.25	103.3	103.25	21.56	7.79	0	12.8	102.5
E100-15-3-5	180.14	143.5	143.54	148.7	143.54	143.5	143.54	143.5	143.54	19.94	29.52	0	22.59	145.5
E100-15-3-6	138.36	109.9	109.88	109.9	109.88	109.9	109.88	109.9	109.88	15.94	13.22	0	14.52	109
E100-15-3-7	161.33	131.5	131.53	131.5	131.53	131.5	131.53	131.5	131.53	16.28	19.1	0	20.79	132.5
E100-15-3-8	171.79	137.2	137.22	137.2	137.22	137.2	137.22	137.2	137.22	15.33	23.42	0	20.25	134.2
E100-15-3-9	183.15	151.5	151.49	152.5	151.49	151.5	151.49	152.5	151.49	23.96	31.76	0	28.18	151.9
E100-15-3-10	219.99	181.6	181.62	189.8	181.62	181.6	181.62	181.6	181.62	31.99	32.65	0	40.93	180.6
E100-15-4-1	218.78	167.6	168.8	167.6	167.55	167.6	167.55	168.8	167.55	0.49	13.7	0	1.16	174.2
E100-15-4-2	260.12	204.1	204.1	204.1	204.1	204.1	204.1	204.1	204.1	9.37	13.97	3.16	0	209.7
E100-15-4-3	236.79	188.1	188.12	190.4	188.12	188.1	188.12	188.1	188.12	24.11	20.55	0	7.17	186.2
E100-15-4-4	302.22	242.2	242.19	247.7	242.19	242.2	242.19	242.2	242.19	5.39	16.7	3.12	0	240.2
E100-15-4-5	299.8	247.4	247.36	247.4	247.36	247.4	247.36	247.4	247.36	4.28	9.74	0.67	0	253.1
E100-15-4-6	283.32	227.1	227.12	227.1	227.12	227.1	227.12	227.1	227.12	3.01	19.02	0	11.63	223
E100-15-4-7	304.86	252.1	252.13	252.1	252.13	252.1	252.13	252.1	252.13	0	9.66	3.2	3.65	248.6
E100-15-4-8	221.48	170.9	170.85	170.9	170.85	170.9	170.85	171.8	170.85	7.09	1.8	0	2.58	174.6
E100-15-4-9	239.15	191	190.96	191	190.96	191	190.96	191	190.96	6.25	12.74	0	3.17	191.9
E100-15-4-10	236.73	193.5	192.52	192.5	192.52	192.5	192.52	193.5	192.52	0	6.41	6.99	0.4	194.3
AVERAGE	**129.63**	**102.3**	**102.27**	**103.6**	**102.1**	**102.1**	**102.37**	**102.9**	**102.1**	**13.56**	**14.92**	**0.43**	**13.35**	**103.1**

Table C.3 SSQR obj. function deviations from UB for 200-activity instances

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E200-1-1-1	0.34	0.12	0.12	0.12	0.12	0.12	0.46	0.46	0	0.46	0	0	0.46	0.3
E200-1-1-2	0	0	0	0	0	0	0	0	0	0	0	0	0	2.98
E200-1-1-3	0	0	0	0	0	0	0	0	0	0	0	0	0	9.21
E200-1-1-4	0.54	0.45	0.08	0.59	0	0.08	0.45	0.51	0.08	0.83	0.65	0.08	0.75	11.18
E200-1-1-5	0.16	0	0	0	0	0	0	0.16	0	0.16	0	0	0.16	11.53
E200-1-1-6	0	0	0	0	0	0	0	0	0	0	0	0	0	1.39
E200-1-1-7	0.14	0	0	0	0	0	0	0	0	0	0	0	0	8.9
E200-1-1-8	0	0.5	0	0.5	0	0	0	0.5	0	0.22	0.33	0	0.55	7.5
E200-1-1-9	0.13	0.13	0	0.34	0	0	0.34	0.34	0	0	0	0	0	3.51
E200-1-1-10	0	0.16	0	0.16	0	0	0.16	0.16	0	0.16	0.16	0	0.16	9.35
E200-1-2-1	4.83	6.43	1.13	6.83	1.27	5.58	5.81	8.56	1.19	1.33	3.76	0	1.79	67.76
E200-1-2-2	8.21	6.01	4.88	6.71	4.34	7.25	6.06	8.33	4.3	0	0.87	1.27	1.21	85.81
E200-1-2-3	7.02	8.35	1.15	5.24	0.17	7.52	4.13	8.94	0.1	2.33	2.88	0	1.13	79.23
E200-1-2-4	3.22	5.59	0.34	4.54	0.57	4.46	2.95	5.19	0.74	1.59	0.38	0	0.21	65.97
E200-1-2-5	4.66	5.66	2.57	5.72	3.59	3.84	4.32	6.33	3.66	0	3.04	2.5	0.53	67.83
E200-1-2-6	8	10.65	1.49	6.25	2.84	8.56	6.66	13.25	2.55	2.93	4.16	0	2.85	65.41
E200-1-2-7	4.87	5.74	2.4	4.39	2	8.01	3.21	6.31	2.49	0	0.86	0.32	0.39	80.47
E200-1-2-8	4.66	5.74	3.86	3.92	2.96	5.85	2.57	6.62	4.02	0	1.2	0.28	1.36	80.69
E200-1-2-9	5.56	4.97	2.74	3.02	2.48	6.22	2.54	5.6	2.56	2	2.17	0	3.26	70.23
E200-1-2-10	7.13	6.89	3.37	5.8	3.33	6.03	4.94	6.57	2.8	0	3.2	2.39	1.8	69.6
E200-1-3-1	4.94	7.28	5.67	7.41	1.53	7.77	3.84	10.56	1.38	0.78	2.46	0	0.79	70.93
E200-1-3-2	5.2	9.93	5.65	10.3	6.05	9.09	5.81	11.36	4.92	0.05	3.39	1.71	0	61.39
E200-1-3-3	6.76	6.7	3.77	7.99	2.38	9.41	4	8.2	2.29	1.32	3.34	4.29	0	71.44
E200-1-3-4	5.2	10.8	3.61	7.73	3.92	9.84	4.71	12.3	2.61	1.74	0.57	1.22	0	76.37
E200-1-3-5	5.01	11.14	6.6	6.67	5.98	10.95	6.08	13.89	7.23	2.83	3.82	0	3.73	82.95
E200-1-3-6	4.85	10.47	5.06	8.63	6.84	10.06	6.03	10.64	6.96	0	3.11	3.65	1.75	76.21
E200-1-3-7	8.8	11.83	7.28	10.17	5.56	10.73	5.57	14.54	4.92	0	4.29	1.86	2.55	63.95
E200-1-3-8	4.39	7.69	4.41	5.66	3.78	6.88	2.04	8.46	3.38	0	3.11	0.92	2.51	76.3
E200-1-3-9	6.07	9.85	7.98	7.23	6.58	10.9	6.93	10.52	7.15	0	4.38	1.04	1.27	87.19
E200-1-3-10	2.12	9.49	5.96	8.27	5.34	8.31	5.07	9.19	4.08	0.27	3.79	2.25	0	68.58
E200-1-4-1	221.55	244.6	242.04	237.5	232.56	248.3	236.54	249.2	229.48	20.32	0	6.21	5.13	413
E200-1-4-2	462.63	509	485.8	485.1	474.56	504	482.02	521.9	467.57	0	85.92	62.2	77.56	821.2
E200-1-4-3	331.39	368.1	350.61	356.6	335.61	362.7	337.78	377.3	337.78	0	49.99	59.2	57.71	622.1
E200-1-4-4	351.42	386.7	364.42	383.6	363.48	390.4	381.02	405.4	369.95	0	65.02	66.9	66.85	644.3
E200-1-4-5	350.22	383.9	364.16	375.4	352.49	385	376.06	386.9	361.81	0	344.5	46.1	337.1	585.3
E200-1-4-6	545.07	601.5	576.76	576.9	581.92	610.8	579.66	606.7	568.04	0	0	99.1	64.21	902.9
E200-1-4-7	386.6	417.7	402.81	415.9	385.83	432.1	406.06	431.6	402.16	0	54.78	61.6	26.82	690.8
E200-1-4-8	375.88	426.1	418.19	420.6	403.57	430.4	411.39	420.6	402.2	0	62.31	51	48.86	666.8
E200-1-4-9	327.03	365.4	351.35	359	339.35	367.6	345.32	376.6	338.02	0	51.83	60.5	41.87	670.7
E200-1-4-10	371.34	414.9	398.95	398.2	393.49	420.8	386.72	417	391.61	0	44.48	52.3	41.08	656.2
AVERAGE	**95.9**	**107**	**100.88**	**103.6**	**98.36**	**107.7**	**100.93**	**109.5**	**98.45**	**0.97**	**20.37**	**14.7**	**19.91**	**205.2**
E200-5-1-1	7.41	0.36	0.3	1.6	0	0.6	0.45	2.57	0	7.52	8	4.73	8.1	46.33
E200-5-1-2	7.92	0.57	0.94	2.07	0.44	0.83	0	2	0.44	8.03	8.05	5.61	6.67	44.06
E200-5-1-3	6.24	1.07	0	2.59	0	0.21	0.65	3.67	0	6.04	4.78	3.65	5.65	43.43
E200-5-1-4	5.71	0.21	0	3.48	0	0.01	0	2.9	0	4.58	4.27	3.58	5.51	44.83
E200-5-1-5	28.58	20.86	21.45	23.75	20.86	20.93	21.49	24.34	20.86	29.84	29.84	0	30.09	64.88
E200-5-1-6	6.94	1.53	0.08	0.31	0.31	0.71	0.43	1.53	0	6.06	6.9	4.45	6.54	33.41
E200-5-1-7	17.14	12.44	11.41	13.13	10.59	11.06	12.98	13.04	10.78	18.11	16.87	0	17.62	58.58

Table C.3 SSQR obj. function deviations from UB for 200-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E200-5-1-8	5.84	0.33	0.1	0.8	0	0.16	0.93	0.82	0	6.84	5.12	4.38	6.73	43.21
E200-5-1-9	6.48	0.33	0	0.43	0	0.36	0.59	1.01	0	34.72	35.72	4.72	8.06	41.25
E200-5-1-10	4.62	0.25	0	3.36	0	0.37	0.37	0.86	0.37	42.59	4.98	3.74	10.21	35.14
E200-5-2-1	10.16	1.01	0.12	0.64	0.05	1.37	0	1.48	0.13	11.47	10.6	7.15	21.12	49.83
E200-5-2-2	10.7	0.9	0	0.9	0.43	0.9	0.24	0.75	0.61	9.39	10.47	7.72	10.28	55.18
E200-5-2-3	7.81	0.1	0.17	0.49	0.08	0.38	0.38	0.54	0	7.75	7.38	59.4	7.39	40.1
E200-5-2-4	10.16	0.95	0.03	0.97	0.16	0.31	0	1.18	0.26	9.81	9.74	7.62	17.39	48.32
E200-5-2-5	10.64	1.11	0.11	0.8	0.18	1.07	0	0.52	0.14	8.65	8.62	7.4	12.77	52.47
E200-5-2-6	8.6	0.91	0.08	0.69	0	0.74	1.44	1.47	0.29	8.99	9.12	6.42	9.47	51.07
E200-5-2-7	8.79	0.97	0	1.02	0.17	1.16	0.78	0.84	0.2	8.85	8.85	6.09	9.96	58.25
E200-5-2-8	11.4	0.76	0.61	0.82	0.26	1.04	0.84	1.21	0	9.09	10.63	7.43	10.14	47.24
E200-5-2-9	11.47	1.04	0	0.41	0.16	0.53	0.35	1.35	0.13	10.66	9.21	6.68	11.04	56.51
E200-5-2-10	9.88	1.52	0	1.27	0.33	0.99	0.99	1.81	0.6	10.8	9.53	6.88	11.19	40.2
E200-5-3-1	14.98	1.98	0.99	1.79	0.25	2.2	0.57	2.47	0	12.09	12.9	12.2	14.04	46.48
E200-5-3-2	12.2	2.41	1.03	1.38	0.09	2.37	0.07	2.14	0	11.11	11.07	8.95	11.18	45.79
E200-5-3-3	12.68	2.81	0.21	2.17	0.62	1.78	0	2.75	0.21	12.41	11.34	8.95	11.05	54.33
E200-5-3-4	14.43	2.48	1.11	4.05	0.66	2.11	2.24	3.48	0	11.92	11.51	10.9	12.68	37.3
E200-5-3-5	12.99	1.11	0	1.5	0.69	1.63	0.35	0.92	0.65	12.3	11.51	10.5	11.95	47.97
E200-5-3-6	12.24	2.72	0.96	1.59	0.23	1.19	0.94	2.61	0	10.7	10.99	10.4	11.13	51.48
E200-5-3-7	13.44	2.13	0	1.78	0.28	2.62	1.01	3.16	0.28	11.49	11.99	11.4	12.73	41.14
E200-5-3-8	14.01	2.67	0.28	2.04	0	1.74	1.58	3.52	0.42	12.15	11.35	10.5	12.43	41.86
E200-5-3-9	14.04	1.83	0.1	2.37	0	1.88	0.57	1.99	0.66	13.2	12.73	10.5	13.16	41.89
E200-5-3-10	11.64	2.14	0	2.41	0.91	0.99	0.91	2.26	0.95	9.4	9.83	9.23	9.82	38.91
E200-5-4-1	16.87	2.84	1.29	0.65	0.72	2.44	0.92	3.87	0	12.96	13.77	15.3	12.84	45.41
E200-5-4-2	16.02	3.74	0	2.31	0.53	2.98	2.3	3.82	1.13	11.8	13.24	13.3	11.78	44.35
E200-5-4-3	13.67	1.49	0	1.63	0	1.63	0	2.63	0.26	10.82	12.52	12.8	11.46	41.43
E200-5-4-4	13.9	1.47	1.69	0.76	0.12	1.69	0	3.96	0.28	16.67	15.61	16.5	16.34	41.71
E200-5-4-5	15.46	1.7	0.97	3.48	0.22	3.86	1.12	4.68	0	12.71	13.75	12.9	13.04	43.66
E200-5-4-6	14.85	2.05	1.03	1.62	0	2.67	1.24	2.6	0.75	20.59	19.48	20.4	20.24	42.9
E200-5-4-7	13.24	1.25	1.35	1.02	0	1.47	1.15	2.21	0	16	14.94	15.8	15.67	40.9
E200-5-4-8	17.67	3.13	0.02	2.88	0	3.51	1.85	4.94	0.23	20.54	19.43	20.3	20.19	46.4
E200-5-4-9	15.62	2.45	2.81	1.02	0.18	0.66	0	2.63	0.44	18.44	17.35	18.3	18.1	43.86
E200-5-4-10	15.52	3.34	2.03	0.89	0	2.87	0.75	3.77	0.2	18.33	17.25	18.1	17.99	43.73
AVERAGE	**12.05**	**2.32**	**1.28**	**2.42**	**0.99**	**2.15**	**1.51**	**3.11**	**1.03**	**13.39**	**12.28**	**10.6**	**12.59**	**45.9**
E200-10-1-1	5.75	0	0	1.12	0	0	0	1.12	0	6.38	5.61	1.12	6.15	15.89
E200-10-1-2	7.57	0	0	1.04	1.04	0	0	1.04	0	6.93	8.35	0	2.47	10.94
E200-10-1-3	7.48	0.08	0	0.08	0	0	0.08	0.08	0	6.22	7.46	0	6.8	12.01
E200-10-1-4	35.15	0	0	0	0	0.24	0	0	0	34.35	36.13	18.2	28.74	8.78
E200-10-1-5	6.28	0.21	0	2.05	0	0.11	1.42	1.99	0	7.12	6.15	0	7.07	9.85
E200-10-1-6	6.8	0	0.1	0	0.1	0.29	0.1	0	0.1	6.16	7.58	0.1	1.73	10.44
E200-10-1-7	6.64	0	0	2.23	0	0	0	3.17	0	7.44	7.44	0	7.34	5.82
E200-10-1-8	6.99	0.07	0	2.15	0	0	0.07	2.15	0	6.35	7.77	0	1.91	17.98
E200-10-1-9	6.58	0.08	0	0.08	0	0	0.08	0.22	0	6.4	6.4	0	6.88	13.6
E200-10-1-10	6.56	0	0	1.82	0	0	0.63	1.71	0	7.32	7.23	0	14.03	11.42
E200-10-2-1	10.61	0.28	0	0.28	0	0.11	0.4	0.4	0	9.83	9.92	8.75	9.83	18.93
E200-10-2-2	10.99	0	0.07	0.07	0	0.32	0.07	0.11	0	2.28	6.7	2.46	5.03	9.19
E200-10-2-3	10.72	0.56	0	0.37	0	0.37	0	0.19	0	13.83	18.66	6.73	6.41	9.33
E200-10-2-4	11.05	0.35	0	0.35	0	0.07	0.35	0.35	0	10.76	11.74	10.8	7.04	12.42
E200-10-2-5	10.47	0	0	0	0	0	0	0	0	7.32	9.36	2.33	4.45	10.88

Table C.3 SSQR obj. function deviations from UB for 200-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E200-10-2-6	9.13	0	0	0.05	0	0	0.05	0.05	0	3.53	5.67	2.94	5.42	11.4
E200-10-2-7	10.45	0.09	0.09	0.21	0.09	0	0	0.21	0.09	10.5	12.11	13.3	12.63	16.93
E200-10-2-8	11.28	0.14	0.14	0	0.14	0.14	0	0.14	0.14	7.77	9.31	0.91	3.91	6.16
E200-10-2-9	9.87	0.2	0	0.16	0	0	0.17	0.51	0	12.09	11	1.46	8.19	10.11
E200-10-2-10	10.13	0	0	0	0	0.34	0	0	0	10.35	13.7	8.88	11.88	9.38
E200-10-3-1	14.46	0.9	0.4	0.89	0.02	0.1	0.04	0.89	0	16.88	18.36	15.2	15.28	29.14
E200-10-3-2	12.57	0.45	0	0.82	0	0	0	0.98	0	11.83	12.31	10.8	12.38	9.08
E200-10-3-3	13.49	0	0	0	0	0.1	0	0	0	11.68	11.89	10.9	12.26	3.11
E200-10-3-4	13.79	0.28	0.03	0.28	0.03	0.03	0	0.32	0.32	15.64	15.42	16.4	15.05	14.62
E200-10-3-5	13.21	0.31	0.31	0	0.31	0.6	0	0.31	0.31	15.05	14.83	15.8	14.46	18.51
E200-10-3-6	14.55	0.44	0.2	1.05	0	0.58	1.23	1.03	0	16.41	16.19	17.2	15.81	10.89
E200-10-3-7	13.91	0.06	0	0.06	0	0.11	0	0.11	0	14.67	14.17	15.7	14.1	5.97
E200-10-3-8	14.33	0.56	0.15	1.54	0.15	0.56	1.05	1.83	0	15.09	14.59	16.2	14.52	13.83
E200-10-3-9	13.86	0.12	0	5.44	0	0	0	5.54	0	14.61	14.12	12.7	14.05	8.03
E200-10-3-10	13.96	0	0	0	0	0	0	0	0	14.71	14.22	12.8	14.15	8.33
E200-10-4-1	18.88	0.41	0.16	0.71	0	0.59	0.45	0.84	0.17	19.67	19.16	17.7	19.08	12.34
E200-10-4-2	16.33	0.21	0.17	0	0.17	0.45	0.1	0.12	0.08	17.1	16.6	15.2	16.53	12.13
E200-10-4-3	16.69	0.88	0.32	0.98	0.27	0.17	0.18	0.82	0	17.46	16.96	15.5	16.88	14.4
E200-10-4-4	17	0.13	0	0.08	0	0.05	0.08	0.05	0.08	17.77	17.26	15.8	17.19	8
E200-10-4-5	16.01	0.4	0.13	0.38	0	0.94	0.57	0.61	0.21	16.77	16.27	14.9	16.2	13
E200-10-4-6	15.82	0	0	0	0.05	0.24	0	0.24	0	16.59	16.09	14.7	16.02	11.24
E200-10-4-7	17.18	0.22	0.22	0.18	0	0.41	0	0.48	0	17.95	17.45	16	17.37	11.98
E200-10-4-8	16.58	0.37	0.27	0.16	0	0.08	0.32	0.63	0.1	17.35	16.85	15.4	16.78	17.76
E200-10-4-9	17.54	0.53	0.69	0.75	0.03	0	0.18	1.38	0.2	18.32	17.81	16.4	17.74	12.2
E200-10-4-10	14.87	0.44	0	0.03	0.28	0.41	0	0.66	0	15.62	15.13	13.7	15.06	8.51
AVERAGE	**12.64**	**0.22**	**0.09**	**0.64**	**0.07**	**0.19**	**0.19**	**0.76**	**0.04**	**12.6**	**13.1**	**9.42**	**11.72**	**11.86**
E200-15-1-1	6.18	0	0	1.24	0	0	0	1.26	0	3.44	5.04	0	4.5	1.42
E200-15-1-2	7.3	0	0	0.72	0	0	0	0.72	0	7.81	6.76	4.87	7.6	1.44
E200-15-1-3	6.93	0	0	0.52	0	0	0	0.52	0	7.44	6.4	4.51	7.23	1.46
E200-15-1-4	6.62	0	0	0	0	0	0	0	0	5.78	1.65	1.5	3.58	0.57
E200-15-1-5	6.92	0	0	0	0	0	0	0	0	7.45	6.37	4.4	7.24	0.74
E200-15-1-6	6.18	0	0	1.44	0	0	0	1.44	0	6.72	5.58	3.61	6.54	0.36
E200-15-1-7	7.1	0	0	0	0	0	0	0	0	5.2	5.2	4.62	2.5	1.02
E200-15-1-8	5.74	0	0	0.89	0	0	0	0.89	0	2.3	1.68	1.61	2.3	0.21
E200-15-1-9	6.65	0	0	0	0	0	0	0	0	4.68	1.83	0.72	2.01	0
E200-15-1-10	6.3	0	0	0.83	0	0	0	0.83	0	1.42	1.33	0.32	5.11	1.33
E200-15-2-1	17.94	6.76	6.76	7.89	6.76	6.76	6.76	8.82	6.76	9.83	9.48	6.57	9.8	0
E200-15-2-2	10.69	0	0	1.1	0	0	0	1.1	0	11.23	6.54	2.8	23.46	5.72
E200-15-2-3	14.67	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	15.2	14.06	5.01	13.25	0
E200-15-2-4	11.13	0	0	2.25	0	0	0	1.05	0	11.65	10.53	3.33	9.73	2.75
E200-15-2-5	10.61	0	0	0	0	0	0	0	0	11.13	10.01	2.82	10.96	0.74
E200-15-2-6	14.07	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92	14.59	13.47	11.5	14.42	0
E200-15-2-7	11.47	0	0	0	0	0	0	0	0	12.01	10.86	7.08	11.83	9.14
E200-15-2-8	15.56	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	16.1	14.96	13	15.92	0
E200-15-2-9	10.34	0	0	0.51	0	0	0	0.51	0	10.82	9.79	4.8	10.66	0.88
E200-15-2-10	10.23	0	0	0	0	0	0	0	0	10.73	9.67	6.19	10.56	0.22
E200-15-3-1	13.21	0	0	0	0	0	0	0	0	13.75	12.6	5.28	13.57	0.18
E200-15-3-2	12.59	0	0	0	0	0	0	0	0	13.14	11.96	9.93	12.96	0.31
E200-15-3-3	13.6	0	0	0	0	0	0	0	0	14.14	12.98	11	13.96	0

Table C.3 SSQR obj. function deviations from UB for 200-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E200-15-3-4	14.76	0	0	0	0	0	0	0	0	15.3	14.15	12.2	15.12	0.27
E200-15-3-5	13.8	0	0	0	0	0	0	0	0	14.37	13.15	11.1	14.18	0
E200-15-3-6	13.19	0.8	0	2.69	0	0	1.19	1.44	0	13.72	12.59	10.7	13.54	0.61
E200-15-3-7	12.83	0.38	0	0.99	0	0	0	0.41	0	22.86	9.67	1.47	10.98	0
E200-15-3-8	12.97	0.18	0	0.18	0	0.18	0	0.18	0	11.85	12.64	9.27	11.62	2.33
E200-15-3-9	8.85	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	6.06	6.64	0	7.14	1.59
E200-15-3-10	13.18	0	0	0.9	0	0	0	0.9	0	11.41	10.96	6.29	10.95	0.15
E200-15-4-1	17.75	0	0	0	0	0	0	0	0	15.31	16.21	15.6	14.78	1.38
E200-15-4-2	17.06	0.16	0	0	0	0.16	0.14	0.16	0	14.49	14.66	15.2	14.4	1.42
E200-15-4-3	17.85	0.17	0	0	0	0	0	0	0	15.59	16.3	16.2	14.85	1.19
E200-15-4-4	15.68	0.12	0	0.08	0	0.12	0	0	0	12.89	13.64	14.5	13.27	0.43
E200-15-4-5	15.8	0	0	0	0	0	0	0	0	13.44	13.9	13.8	14.68	0.51
E200-15-4-6	16.43	0	0	0.58	0	0	0	0	0	14.98	15.1	14.4	14.57	0.9
E200-15-4-7	16.15	0	0	0	0	0	0	0	0	14.57	14.57	15.4	14.25	0
E200-15-4-8	18.71	0	0.08	0.08	0	0.12	0	0.12	0	15.37	16.36	15.6	15.65	0.28
E200-15-4-9	17.27	0	0	0	0	0	0.47	0.47	0	14.39	16.38	15.3	14.24	0.38
E200-15-4-10	16.12	0	0	0.31	0	0	0	0	0	13.67	14.82	15.2	14.09	0.57
AVERAGE	**12.26**	**0.52**	**0.48**	**0.89**	**0.48**	**0.49**	**0.52**	**0.83**	**0.48**	**11.42**	**10.51**	**7.94**	**11.2**	**1.01**

Table C.4 SSQR obj. function deviations from UB for 500-activity instances

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E500 1-1-1	2.15	2.44	1.2	3.43	0.11	2	1.66	3.78	0.26	1.44	1.64	0	1.96	74.25
E500 1-1-2	1.97	1.54	1.42	3.27	1.06	2.15	1.42	3.56	0.4	1.46	2.18	0	1.36	88.68
E500 1-1-3	3.42	3.37	1.16	3.07	1.05	2.94	2.41	3.81	0.88	2.06	2.41	0	2.68	76.82
E500 1-1-4	2.93	3.47	0.82	3.87	0.91	2.66	2.41	4.66	0.81	2.8	3.26	0	2.97	83.75
E500 1-1-5	2.36	3.1	0.68	2.82	0	2.69	2.23	4.17	0.23	2.05	1.85	0.39	2.62	75.31
E500 1-1-6	1.31	1.91	1.48	1.98	1.87	2.29	1.73	2.03	2.05	1.02	1.03	0	1.41	93.8
E500 1-1-7	2.84	3.76	0.64	3.89	0.3	3.34	3.61	4.18	0.53	3.03	2.75	0	3.09	55.67
E500 1-1-8	3.6	3.82	1.57	3.79	0.96	2.82	2.71	4.44	0.8	2.34	2.83	0	2	62.12
E500 1-1-9	1.66	1.91	1.56	2.7	0.3	2.14	1.34	3.2	0.65	1.44	2.58	0	0.91	78.28
E500 1-1-10	2.94	2.81	1.01	3.05	0.63	2.56	1.77	3.41	0.77	1.62	1.69	0	2.13	42.32
E500 1-2-1	1.41	4.07	0.97	2.9	0.66	3.91	3.31	4.83	1.27	1.55	1.83	0	1.93	68.85
E500 1-2-2	5.4	7.85	1.85	7.76	1.59	6.11	5.85	9.24	1.62	2.36	3.29	0	3.01	90.5
E500 1-2-3	4.38	6.63	1.25	5.45	0.43	5.91	3.96	7.56	0.5	2.94	3.54	0	2.49	78.04
E500 1-2-4	4.53	5.76	2.39	6.05	1.91	5.86	4.66	6.62	2.45	3.48	3.77	0	4.22	93.42
E500 1-2-5	3.67	4.46	2.26	3.79	1.41	4.49	3.24	6.11	1.62	1.67	2.25	0	1.83	77.24
E500 1-2-6	3.63	5.63	2.94	6.48	1.86	5.1	4.9	6.58	2.12	2.67	2.65	0	3.2	85
E500 1-2-7	2.5	4.24	2.87	4.48	2.15	4.07	3.52	4.4	2.22	1.7	1.71	0	2.18	93.66
E500 1-2-8	2.69	4.19	1.17	4.05	0.62	3.88	2.44	5.38	1.31	1.08	2.05	0	1.55	96.44
E500 1-2-9	2.86	4.59	2.24	5.45	2.88	4.96	3.79	6.33	2.91	2.8	1.3	0	2.82	82.96
E500 1-2-10	3.06	3.86	1.14	3.05	0.4	3.13	2.82	4.88	1.34	1.71	0.9	0	1.48	87.45
E500 1-3-1	4.68	8.35	3.29	6.08	1.67	6.87	2.61	8.83	1.94	2.08	2.47	0	2.27	83.58
E500 1-3-2	3.19	6.89	1.33	4.64	0.07	6.56	3.35	7.39	0	1.42	3.2	1.49	2.25	90.41
E500 1-3-3	3.35	7.42	3.13	4.79	2.63	7.3	3.39	7.67	1.92	0	1.77	0.05	1.02	72.07
E500 1-3-4	4.81	9.4	3.22	5.97	1.95	7.37	4.58	9.09	1.4	1.68	3.26	0	2.79	89.42
E500 1-3-5	4.1	6.18	0.97	5.14	0.51	5.13	2.52	7.51	0.81	1.57	1.72	0	1.77	86.45
E500 1-3-6	3.01	5.54	2.2	5.45	1.17	4.97	1.81	6.99	1.03	0.87	1.13	0	1.95	84.46
E500 1-3-7	3.36	6.39	2.3	5.08	1.68	5.2	2.85	6.21	1.6	0	2.51	0.53	0.57	85.05
E500 1-3-8	1.78	6.86	0.93	4.93	0.67	5.52	3.29	7.11	0.47	0.31	2.05	0	0.45	82.18
E500 1-3-9	4.97	7.14	2.59	6.47	1.56	6.73	3.64	8.47	0.78	2.12	2.77	0	1.59	87.85
E500 1-3-10	1.52	5.59	2.65	3.39	0.26	5.28	1.85	5.98	1.48	0	1.57	1.02	1.17	81.65
E500 1-4-1	2.1	12.36	6.19	7.29	6.68	11.92	6.47	12.09	5.51	0	1.59	2.38	0.44	82.64
E500 1-4-2	2.28	13.17	6.12	8.17	5.75	11.65	7.15	12.31	5.1	0.03	2.19	1.45	0	82.92
E500 1-4-3	1.71	11.25	5.7	9.41	4.39	10.41	5.66	12.49	5.15	0.59	2.22	2.27	0	81.87
E500 1-4-4	3.23	12.17	5.16	7.88	4.2	12.28	6.48	12.97	5.86	0	1.73	2.47	0.68	84.55
E500 1-4-5	3.53	12.15	6.7	10.59	6.33	11.65	7.76	13.75	4.7	0	1.45	0.9	0.07	85.05
E500 1-4-6	2.52	9.59	5.41	8.64	5.59	11.49	5.34	11.57	6.2	1.1	1.66	1.94	0	83.2
E500 1-4-7	3.15	12.88	6.18	7.9	5.83	11.47	7.85	13.28	5.26	1.14	1.39	2.49	0	84.29
E500 1-4-8	3.58	13.33	7.22	9.83	6.13	13.07	8.94	13.05	6.79	0	2.35	3.69	0.76	85.02
E500 1-4-9	2.66	12.47	6.04	7.42	4.86	10.67	5.15	12.15	4.89	0.57	2.14	2.06	0	83.34
E500 1-4-10	2.69	10.54	5.49	6.5	4.76	11.54	6.12	11.21	5.21	0.38	1.69	1.92	0	83.35
AVERAGE	**3.04**	**6.73**	**2.84**	**5.42**	**2.19**	**6.25**	**3.91**	**7.48**	**2.27**	**1.38**	**2.16**	**0.63**	**1.59**	**81.6**
E500 5-1-1	0	48.47	47.87	58.57	47.98	48.24	48	59.16	47.88	10.66	9.17	6.28	9.74	36.24
E500 5-1-2	9.12	56.48	55.41	57.18	55.1	55.73	55.02	57.77	55.06	11.71	8.46	0	11.01	45.66
E500 5-1-3	2.42	42.41	41.72	43.77	41.72	42.15	42.26	43.81	41.75	4.02	2.64	0	3.42	38.27
E500 5-1-4	2.87	40.97	40.95	41.58	40.65	41.17	40.62	41.1	40.68	2.85	1.56	0	3.27	40.95
E500 5-1-5	4.4	40.88	40.11	41.47	40.22	40.58	40.95	41.98	40	7.11	5.36	0	7.43	50.7
E500 5-1-6	2.83	45.43	44.97	49.65	45.11	45.36	45.28	49.92	45.17	3.19	0.76	0	2.83	48.54
E500 5-1-7	4.99	49.87	49.32	50.46	49.06	49.98	49.45	50.7	49.22	3.77	3.91	0	4	42.13

Table C.4 SSQR obj. function deviations from UB for 500-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E500 5-1-8	4.65	42.08	41.04	41.69	41.01	41.67	41.57	42.09	40.75	4.61	3.13	0	5.14	46.92
E500 5-1-9	8.12	50.49	48.95	51.26	48.52	49.23	49.63	51.25	48.68	9.54	8.81	0	10	43.42
E500 5-1-10	3.21	42.89	42.24	43.37	41.96	42.81	43.09	43.11	42.09	5.09	2.66	0	4.55	33.32
E500 5-2-1	6.53	33.47	31.97	34.26	32.16	33.04	33.09	34.76	32.3	5.85	5.37	0	6.26	44.9
E500 5-2-2	2.9	37.44	36.57	37.52	36.48	37.47	37.51	37.7	36.76	5.19	4.62	0	5.59	44.25
E500 5-2-3	5.5	35.48	35.1	36.1	34.78	35.3	35.27	35.73	34.69	5.46	5.82	0	6.91	37.1
E500 5-2-4	4.95	36.66	35.61	37.76	35.63	36.54	36.8	37.9	35.71	4.79	3.57	0	6.9	41.3
E500 5-2-5	3.12	35.54	35.47	35.56	34.94	35.86	35.14	37.04	35.12	1.86	2.79	0	2.75	42.09
E500 5-2-6	6.5	38.78	36.84	37.48	36.74	37.55	37.89	38.67	36.81	6.84	5.65	0	5.61	48.15
E500 5-2-7	4.92	34.61	34.02	35.16	33.78	34.4	34.4	35.39	33.52	5.37	3.91	0	6.95	52.62
E500 5-2-8	6.27	35.8	33.92	41.01	33.47	35.52	34.19	41.27	33.68	7.05	5.37	0	7.58	40.45
E500 5-2-9	4.91	38.59	37.09	38.35	36.87	38.01	37.86	39.07	36.95	5.3	5.27	0	7.07	47.28
E500 5-2-10	4.16	34.04	31.99	32.81	32.05	33.66	32.96	33.83	31.97	4.08	3.11	0	5.26	32.9
E500 5-3-1	3.43	25.83	24.21	25.07	24.93	25.74	24.95	25.86	24.66	1.59	2.67	0	2.12	31.77
E500 5-3-2	5.48	27.57	26.98	29.81	26.24	27.97	26.58	30.02	26.25	1.45	3.86	0	4.13	37.06
E500 5-3-3	5.33	27.78	26.64	28.2	25.84	27.61	26.66	28.93	26.21	2.03	2.49	0	4.16	44.27
E500 5-3-4	5.39	27.42	26.62	29.76	26.69	26.87	27.37	30.4	27	3.77	3.52	0	5.85	26.47
E500 5-3-5	5.73	24.94	22.26	24.31	22.75	23.7	22.54	25.61	22.72	2.4	3.67	0	5.52	38.46
E500 5-3-6	4.11	23.74	21.81	23.28	21.71	23.51	22.15	25.58	22.43	3.14	3.51	0	3.88	40.51
E500 5-3-7	5.35	23.27	22.47	25.59	22.26	23.09	23.22	24.5	22.44	3.26	1.68	0	4.53	31.08
E500 5-3-8	9.35	30.2	28.88	30.02	28.92	29.27	29.88	32.14	28.72	6.34	7.64	0	8.35	36.05
E500 5-3-9	5.68	30.94	29.74	35.46	29.03	30.75	30.03	34.42	29.15	2.31	2.81	0	2.55	31.49
E500 5-3-10	8.01	31	30.46	32.84	30.74	31.44	30.67	33.37	30.37	3.59	1.23	0	5.14	34.38
E500 5-4-1	4.87	21.95	20.06	20.71	20.27	21.94	19.41	22.2	20.11	0	1.21	4.24	1.88	30.49
E500 5-4-2	6.05	18.6	18.6	17.74	16.07	18.09	17.02	18.78	15.92	0.09	2.81	1.05	0	31.95
E500 5-4-3	8.6	22.63	20.61	21.46	20.29	22.12	20.38	23.09	20.45	0	3.05	4.03	2.16	35.13
E500 5-4-4	4.48	18.83	16.52	17.57	15.84	18.72	16.93	18.58	16.04	0	0.96	2.56	0.93	30
E500 5-4-5	5.24	22.42	20.18	21.48	20.02	22.6	19.79	22.37	19.6	1.12	1.36	1.45	0	30.94
E500 5-4-6	5.89	19.76	17.62	18.74	17.52	19.48	17.92	20.1	17.9	2.14	0.2	3.55	0	31.76
E500 5-4-7	8.01	16.93	13.34	15.42	12.77	15.4	14.16	16.22	13.22	1.16	0	3.83	0.34	34.39
E500 5-4-8	6.55	18.48	16.67	17.68	15.98	18.43	17.04	18.32	16.1	0	1.54	3.16	2.64	32.57
E500 5-4-9	7.86	16.58	12.32	13.68	11.31	14.87	12.37	16.87	11.83	0	1.52	3.4	0.31	34.21
E500 5-4-10	5.32	17.43	15.91	17.43	15.26	18.12	15.84	18.25	15.12	1.24	0.55	2.73	0	31.05
AVERAGE	**5**	**32**	**31**	**33**	**31**	**32**	**31**	**33**	**31**	**4**	**3**	**1**	**4**	**38**
E500 10-1-1	4.07	57.29	57.4	62.36	57.32	57.37	57.32	62.42	57.37	4.72	4.94	0	4.91	14.04
E500 10-1-2	7.56	66.08	65.9	66.14	65.93	66.02	66.02	66.16	65.9	7.53	5.53	0	7.82	10.93
E500 10-1-3	8.42	72.89	72.96	74.14	72.96	72.96	72.89	74.06	72.96	7.17	7.6	0	8.7	12.99
E500 10-1-4	9.87	82.08	82.01	83.15	82.01	82.01	82.08	83.27	82.01	7.29	7	0	7.59	8.23
E500 10-1-5	4.09	64.5	64.65	70.77	64.5	64.5	72.38	72.38	64.5	3.39	4.83	0	4.4	7.59
E500 10-1-6	3.22	60.53	60.49	62.05	60.49	60.49	60.53	62.05	60.49	4.11	3.78	0	4.44	6.74
E500 10-1-7	9.45	80.06	80.06	80.21	80.06	80.06	80.06	80.21	80.06	9.52	9.98	0	9.81	8.6
E500 10-1-8	4.64	66.98	66.95	77.84	66.95	66.98	66.98	77.84	66.98	3.85	3.75	0	4.41	15.4
E500 10-1-9	9.11	85.94	85.83	85.94	85.83	85.9	85.94	85.94	85.9	2.44	2.57	0	2.87	16.3
E500 10-1-10	4.61	63.68	63.57	71.24	63.57	63.57	63.66	71.19	63.57	8.91	4.78	0	6.28	9.39
E500 10-2-1	5.54	49.07	49.16	52.1	49.15	49.32	49.07	52.2	49.17	6.82	6.06	0	7.08	13.48
E500 10-2-2	5.43	61.23	61.21	61.23	61.21	61.23	61.21	61.23	61.21	3.82	3.4	0	5.98	3.71
E500 10-2-3	4.15	56.56	56.49	60.69	56.34	56.55	56.55	60.03	56.41	5.11	5.3	0	6.83	2.85
E500 10-2-4	5.2	54.87	54.79	57.06	54.79	54.79	55.49	57.08	54.79	4.51	4.55	0	5.41	6.51
E500 10-2-5	7.94	50.02	49.95	50.83	49.95	50.03	50.03	50.62	49.95	7.03	7.89	0	7.54	8.34

Table C.4 SSQR obj. function deviations from UB for 500-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E500 10-2-6	5.01	53.49	52.98	53.4	52.98	53.14	53.05	53.63	53.07	5.31	4.69	0	5.75	7.19
E500 10-2-7	6.71	62.84	62.78	66.57	62.53	63.04	62.6	62.6	62.56	7.12	5.31	0	9.13	12.98
E500 10-2-8	6.73	56.07	55.99	56.35	55.99	56.02	56.1	56.1	55.99	7.69	5.87	0	7.66	1.83
E500 10-2-9	5.91	48.68	48.18	49.51	48.09	48.25	48.56	49.81	48	5.45	6.23	0	6.58	6.14
E500 10-2-10	5.84	53.98	53.98	54.69	53.98	53.98	53.98	54.92	53.98	5.66	5.08	0	5.83	5.11
E500 10-3-1	7.63	41.17	40.49	41.96	40.48	40.51	40.49	42.71	40.49	4.38	5.04	0	4.04	21.43
E500 10-3-2	7.61	37.25	36.9	37.68	36.8	37.11	36.92	37.84	36.89	4.73	4.03	0	6.41	4.27
E500 10-3-3	6.97	46.63	46.45	49.56	46.61	46.56	46.38	49.78	46.5	3.71	4.75	0	5.05	0.15
E500 10-3-4	7.64	39.66	39.41	41.46	39.52	39.59	39.38	41.55	39.38	5.64	5.36	0	5.67	8.43
E500 10-3-5	3.87	44.17	43.5	44.17	43.67	43.89	43.88	44.17	43.67	4.69	6.63	0	6.79	8.73
E500 10-3-6	8.54	42.44	42.39	47.57	42.52	42.44	42.55	47.16	42.42	1.87	5.11	0	4.56	5.07
E500 10-3-7	10.75	38.89	38.5	39.54	38.54	38.8	38.42	40.13	38.71	4.98	5.8	0	6.51	3.03
E500 10-3-8	7.8	36.89	36.35	36.87	36.87	37.16	36.1	37.46	36.03	6.35	5.92	0	5.65	7.33
E500 10-3-9	5.66	31.57	31.55	33.28	31.57	31.57	31.55	33.28	31.55	1.08	2.42	0	4.34	0.25
E500 10-3-10	7.31	38.52	38.4	38.79	38.4	38.52	38.52	38.95	38.23	3.56	3.56	0	4.4	2.01
E500 10-4-1	9.84	28.98	28.61	28.83	28.59	29.11	28.61	29.02	28.28	0	4.8	7.02	2.45	3.79
E500 10-4-2	8.88	21.17	20.68	21.22	20.71	21.18	20.71	21.32	20.82	0.86	3.26	2.03	0	4.94
E500 10-4-3	4.08	24.36	23.24	24.05	23.46	24.92	23.62	24.37	23.48	0.38	0.97	1.29	0	2.04
E500 10-4-4	7.58	20.37	20.18	20.05	19.78	20.39	20.17	20.48	20.11	0	1.61	3.32	0.13	0.09
E500 10-4-5	7.2	22.12	21.98	22.3	21.74	22.24	21.62	22.3	21.66	0.54	2.37	3.08	0	4.42
E500 10-4-6	9.21	26.15	25.99	26.09	25.97	26.15	25.99	26.17	25.9	0.7	1.37	5.43	0	4.89
E500 10-4-7	8.25	24.34	23.96	24.39	24.01	24.37	24.1	24.51	23.95	0	3.99	0.64	0.59	3.45
E500 10-4-8	7.29	19.51	19.33	19.46	19.18	19.27	19.22	19.56	19.2	0	1.01	1.44	1.29	8.37
E500 10-4-9	9.17	27.29	27.22	27.39	27.03	27.39	27.32	27.66	27.32	0	3.46	3.82	1.36	4.21
E500 10-4-10	13.71	30.47	30.23	30.36	30.21	30.16	30.1	30.29	30.19	0	7.79	9.09	5.36	7.42
AVERAGE	**7.06**	**47.22**	**47.02**	**48.78**	**47.01**	**47.19**	**47.25**	**48.81**	**46.99**	**4.02**	**4.71**	**0.93**	**4.84**	**7.07**
E500 15-1-1	2.73	52.94	52.94	68.76	52.94	52.94	52.94	68.76	52.94	3.3	3.6	0	3.9	1.11
E500 15-1-2	4.21	61.22	61.22	76.08	61.22	61.22	75.07	76.08	61.22	4.89	4.88	0	5.65	4.5
E500 15-1-3	5.04	62.56	62.56	74.15	62.56	62.56	62.92	67.14	62.56	4.9	5.46	0	5.48	5.34
E500 15-1-4	2.66	58.03	58.03	58.1	58.03	58.03	58.03	58.1	58.03	2.6	3.25	0	2.9	0.06
E500 15-1-5	3.16	59.15	59.15	59.69	59.15	59.15	59.15	59.69	59.15	3.54	4.35	0	4.17	3.46
E500 15-1-6	2.28	59.34	59.34	90.25	59.34	59.34	59.34	90.25	59.34	2.12	3.2	0	2.75	2.62
E500 15-1-7	3.51	56.92	56.92	65.68	56.92	56.92	65.68	65.68	56.92	3.7	2.83	0	3.7	0.17
E500 15-1-8	3.52	53.67	53.67	61.23	53.67	53.67	53.67	54.56	53.67	5.78	4.16	0	5.84	0.15
E500 15-1-9	1.76	57.07	57.07	74.98	57.07	57.07	57.07	74.98	57.07	1.66	1.27	0	1.54	0.65
E500 15-1-10	3.37	52.13	52.13	52.22	52.13	52.13	52.13	52.22	52.13	4.15	3.94	0	5.24	2.2
E500 15-2-1	5.85	45.12	45.12	48.95	45.12	45.12	45.12	48.95	45.12	6.17	6.47	0	6.67	0.59
E500 15-2-2	5.54	46.64	46.64	51.04	46.64	46.64	46.64	50.58	46.64	5.17	5.59	0	7.1	17.71
E500 15-2-3	5.69	45.05	45.05	45.44	45.05	45.05	45.05	45.44	45.05	5.4	6.04	0	6.11	4.38
E500 15-2-4	4.72	46.16	46.16	48.28	46.16	46.16	46.16	48.28	46.16	4.36	3.94	0	4.32	3.39
E500 15-2-5	5.46	47.35	47.31	48.07	47.31	47.35	47.31	48.07	47.31	5.93	5.56	0	7.46	5.79
E500 15-2-6	5.57	54.52	54.47	59.93	54.47	54.52	54.52	59.99	54.52	5.53	5.23	0	6.29	5.89
E500 15-2-7	5.12	42.66	42.66	42.66	42.66	42.66	42.66	42.66	42.66	3.36	4.03	0	4.31	5.46
E500 15-2-8	4.08	45.99	45.99	46.19	45.99	45.99	45.99	46.19	45.99	4.81	3.64	0	5.8	4.4
E500 15-2-9	5.98	48.72	51.16	48.72	48.72	48.72	48.72	51.16	48.72	3.96	5.62	0	6.01	6.29
E500 15-2-10	4.25	52.15	52.15	54.38	52.15	52.15	53	53.89	52.15	4.54	3.47	0	4.75	4.56
E500 15-3-1	8.29	39.93	39.93	41.24	39.93	39.93	39.93	41.24	39.93	4.77	5.76	0	7.22	8.63
E500 15-3-2	6.1	35.79	35.79	37.74	35.85	35.85	35.79	37.74	35.79	2.07	3.82	0	3.85	6.44
E500 15-3-3	6.16	34.95	34.95	35.98	34.95	34.95	34.95	35.98	34.95	3.86	4.44	0	4.88	6.5

Table C.4 SSQR obj. function deviations from UB for 500-activity instances (cont'd)

Project Name	SSQR Objective Function Deviation from UB (%)													
	MSP 2019	PRIMAVERA P6 2019								ASTA 2019				SSS
	S	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID
E500 15-3-4	7.77	36.27	36.27	36.27	36.27	36.27	36.27	36.27	36.27	4.37	7.77	0	6.59	8.11
E500 15-3-5	7.66	34.44	34.44	37.36	34.44	34.44	34.44	37.36	34.44	4.21	4.97	0	4.4	8.02
E500 15-3-6	6.36	41	41	42.04	41	41	41	42.04	41	2.67	5.68	0	3.93	6.69
E500 15-3-7	7.79	34.82	34.82	35.88	34.82	34.82	34.82	35.88	34.82	5.16	5.69	0	5.81	6.03
E500 15-3-8	8.96	34.99	35.05	35.87	34.98	35.07	34.98	35.69	34.99	6.2	7.3	0	7.54	7.66
E500 15-3-9	8.17	35.52	35.52	35.58	35.52	35.52	35.52	35.58	35.52	6.34	6.41	0	7.92	6.47
E500 15-3-10	7.6	43.48	43.48	44.82	43.48	43.48	43.48	44.82	43.48	4.11	6.13	0	5.27	5.48
E500 15-4-1	10.72	27.69	27.77	27.77	27.69	27.69	27.69	27.69	27.69	0.23	0	2.22	2.91	7.93
E500 15-4-2	6.67	20.01	20.01	20.01	20.01	20.01	20.01	20.01	20.01	0	2.34	2.37	0.91	4.24
E500 15-4-3	7.24	20.88	20.81	20.81	20.81	20.81	20.81	20.81	20.81	0.87	2.61	2.25	0	4.51
E500 15-4-4	6.39	17.57	17.53	17.57	17.53	17.57	17.59	17.57	17.53	0	2.06	0.81	0.86	4.17
E500 15-4-5	6.07	23.34	23.21	23.34	23.21	23.34	23.21	23.34	23.21	0.03	0.84	0.39	0	5.04
E500 15-4-6	8.52	17.69	17.64	17.69	17.64	17.64	17.64	17.69	17.64	0.82	3.32	5.26	0	6.78
E500 15-4-7	6.2	25.11	25.12	25.4	25.08	25.08	25.08	25.4	25.08	0	3.53	4.34	0.55	4.46
E500 15-4-8	5.45	20.25	20.25	20.25	20.25	20.25	20.25	20.25	20.25	0	1.13	0.38	0.76	2.73
E500 15-4-9	8.13	24.07	23.9	23.9	24.07	23.9	23.9	23.9	23.9	0	3.69	2.95	0.7	5.34
E500 15-4-10	6.89	15.69	15.54	15.98	15.53	15.7	15.53	15.82	15.54	0	2.7	1.69	1.07	5.02
AVERAGE	**5.79**	**40.77**	**40.82**	**44.26**	**40.76**	**40.77**	**41.35**	**43.94**	**40.76**	**3.29**	**4.17**	**0.57**	**4.13**	**4.98**

APPENDIX D

MINIMUM MAKESPAN VALUES

Table D.1 Minimum makespans for 50-activity instances

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 1-1-1	29	196	176	173	172	189	181	176	171	181	228	216	224	208	232	171
E50 1-1-2	25	228	211	225	205	221	203	207	212	220	240	237	240	242	243	203
E50 1-1-3	25	208	180	190	180	203	171	176	186	194	233	218	228	233	292	171
E50 1-1-4	16	206	184	187	182	199	186	189	182	198	223	199	207	211	239	182
E50 1-1-5	25	184	169	175	158	180	171	171	157	175	200	200	193	231	190	157
E50 1-1-6	21	247	227	233	232	225	222	227	230	230	268	250	250	265	290	222
E50 1-1-7	31	205	175	185	181	205	192	182	182	192	219	223	220	219	240	175
E50 1-1-8	31	193	160	154	158	154	161	160	155	165	197	174	182	185	234	154
E50 1-1-9	22	181	170	164	157	165	155	161	152	167	211	194	180	222	198	152
E50 1-1-10	34	222	198	198	193	208	202	196	197	213	227	222	224	236	267	193
E50 1-2-1	28	216	189	182	177	200	185	189	187	203	216	215	238	222	247	177
E50 1-2-2	27	228	193	205	199	201	186	196	184	190	232	212	212	229	231	184
E50 1-2-3	26	184	173	169	166	180	172	172	166	179	189	194	199	203	195	166
E50 1-2-4	30	243	216	221	208	226	214	206	209	231	252	255	246	249	269	206
E50 1-2-5	23	190	176	168	166	174	184	166	168	175	211	214	227	200	227	166
E50 1-2-6	24	185	176	173	171	198	170	179	169	193	200	202	209	223	195	169
E50 1-2-7	34	231	199	230	197	214	207	189	194	219	239	244	233	228	274	189
E50 1-2-8	33	235	160	154	158	154	161	160	155	165	234	231	238	242	269	154
E50 1-2-9	23	174	158	163	159	166	159	161	159	160	185	186	175	179	236	158

Table D.1 Minimum makespans for 50-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 1-2-10	27	217	199	196	191	201	194	193	189	201	227	220	225	225	218	189
E50 1-3-1	28	163	141	145	143	139	142	144	138	154	182	170	168	169	254	138
E50 1-3-2	34	217	199	206	211	206	184	212	192	213	231	216	218	227	290	184
E50 1-3-3	33	208	199	211	199	218	194	202	188	209	221	211	224	223	238	188
E50 1-3-4	33	198	187	182	179	193	182	185	181	186	209	194	209	203	219	179
E50 1-3-5	28	242	211	220	215	219	203	222	197	227	252	232	251	248	283	197
E50 1-3-6	33	207	171	193	177	184	171	177	170	178	203	186	204	203	234	170
E50 1-3-7	31	226	222	219	213	236	205	212	205	221	245	223	245	245	257	205
E50 1-3-8	33	213	204	197	202	201	193	204	189	204	227	230	222	219	237	189
E50 1-3-9	25	190	168	159	161	180	166	175	157	174	206	192	200	208	239	157
E50 1-3-10	36	232	202	204	194	222	203	208	194	228	236	236	226	217	246	194
E50 1-4-1	33	180	158	162	172	176	157	166	155	172	192	186	189	195	220	155
E50 1-4-2	26	171	153	155	148	162	150	166	151	160	190	178	203	186	237	148
E50 1-4-3	34	200	183	180	173	208	170	194	176	201	208	206	211	209	257	170
E50 1-4-4	35	169	158	156	155	165	154	158	152	170	180	180	181	186	260	152
E50 1-4-5	34	149	140	145	140	147	135	142	128	140	184	166	179	180	272	128
E50 1-4-6	39	199	192	203	183	195	187	180	178	195	213	209	209	217	235	178
E50 1-4-7	35	208	189	205	191	224	183	209	188	201	219	224	212	225	207	183
E50 1-4-8	34	207	186	191	188	196	181	189	180	197	207	203	209	211	263	180
E50 1-4-9	33	186	172	175	176	181	164	171	172	181	193	196	206	192	221	164
E50 1-4-10	42	212	202	189	186	200	191	197	186	211	224	212	209	229	234	186
E50 5-1-1	25	202	239	243	234	251	236	239	228	237	220	207	213	216	275	202
E50 5-1-2	18	165	218	217	207	222	210	220	214	217	171	182	190	178	253	165
E50 5-1-3	29	201	217	229	224	237	217	223	215	234	195	195	191	188	236	188
E50 5-1-4	22	203	252	244	238	264	234	250	239	264	211	217	211	225	283	203
E50 5-1-5	24	192	237	251	231	248	227	241	223	245	180	194	190	200	270	180
E50 5-1-6	28	188	219	230	215	227	232	224	211	231	204	193	204	193	255	188

Table D.1 Minimum makespans for 50-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 5-1-7	32	183	224	223	216	245	230	220	220	246	187	189	190	188	253	183
E50 5-1-8	27	236	288	275	269	291	278	288	270	287	242	243	243	250	302	236
E50 5-1-9	31	185	222	219	218	225	230	228	216	220	188	182	189	194	255	182
E50 5-1-10	23	168	226	224	216	231	225	227	218	225	186	169	181	174	242	168
E50 5-2-1	26	180	243	238	248	246	240	245	229	241	203	185	205	186	266	180
E50 5-2-2	27	213	272	264	259	280	267	275	251	277	218	210	221	222	283	210
E50 5-2-3	28	203	232	247	226	244	232	229	228	250	210	211	207	200	248	200
E50 5-2-4	32	203	236	249	227	255	246	228	229	257	209	204	201	196	277	196
E50 5-2-5	34	221	285	273	269	278	277	283	268	270	215	212	232	225	298	212
E50 5-2-6	26	191	227	226	223	228	227	231	210	227	187	180	185	185	235	180
E50 5-2-7	27	199	260	239	243	265	249	261	243	265	197	205	205	217	263	197
E50 5-2-8	35	218	263	267	259	276	254	273	258	276	222	214	210	218	281	210
E50 5-2-9	33	203	251	240	237	250	253	248	239	247	199	209	207	208	262	199
E50 5-2-10	32	208	253	246	241	259	252	255	243	259	211	223	221	209	270	208
E50 5-3-1	30	198	245	247	243	247	248	249	243	247	200	207	194	200	267	194
E50 5-3-2	32	207	265	276	266	269	247	273	256	271	223	217	221	224	292	207
E50 5-3-3	29	192	268	258	254	250	231	254	249	249	204	197	204	206	286	192
E50 5-3-4	34	221	261	280	262	297	261	286	257	288	224	220	235	229	294	220
E50 5-3-5	29	186	220	220	217	222	212	220	210	220	187	178	178	174	226	174
E50 5-3-6	34	180	245	236	222	234	227	242	225	234	187	183	185	184	250	180
E50 5-3-7	26	202	248	239	237	251	245	248	236	248	228	205	206	202	261	202
E50 5-3-8	36	195	263	253	250	249	252	257	238	251	212	197	209	208	278	195
E50 5-3-9	30	220	287	306	296	300	273	296	280	300	239	242	246	227	304	220
E50 5-3-10	37	205	286	302	289	300	284	302	292	298	220	228	231	229	310	205
E50 5-4-1	32	212	271	257	260	275	261	263	261	272	210	215	205	208	278	205
E50 5-4-2	32	174	219	225	211	230	215	219	217	235	177	172	180	185	237	172
E50 5-4-3	37	199	273	252	242	255	255	258	251	255	210	206	202	203	258	199
E50 5-4-4	40	222	272	293	268	279	269	287	273	277	223	222	221	211	303	211
E50 5-4-5	37	193	244	247	246	243	233	229	221	240	199	217	206	199	254	193

Table D.1 Minimum makespans for 50-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 5-4-6	38	204	258	269	265	269	244	267	249	266	196	199	191	203	276	191
E50 5-4-7	35	206	269	267	266	278	267	272	255	278	205	207	196	211	280	196
E50 5-4-8	32	213	261	267	247	264	261	261	258	261	208	209	210	211	271	208
E50 5-4-9	31	188	235	240	222	241	231	245	217	252	193	192	205	197	268	188
E50 5-4-10	32	195	244	227	235	262	242	254	226	240	195	188	195	207	250	188
E50 10-1-1	27	241	307	306	306	309	306	304	306	306	256	244	251	243	309	241
E50 10-1-2	33	237	307	298	300	310	307	307	309	307	235	235	245	236	300	235
E50 10-1-3	21	199	268	276	267	276	268	268	262	268	225	204	213	212	276	199
E50 10-1-4	25	194	250	247	246	247	250	250	247	248	206	193	207	202	249	193
E50 10-1-5	36	209	297	290	277	298	286	290	279	297	252	226	246	252	298	209
E50 10-1-6	21	201	281	281	280	281	281	281	281	281	238	211	225	229	281	201
E50 10-1-7	17	213	270	272	274	275	275	270	274	275	237	221	222	227	275	213
E50 10-1-8	29	226	256	256	255	256	256	256	255	256	224	219	227	221	256	219
E50 10-1-9	30	225	269	276	271	276	275	269	270	275	247	237	246	247	276	225
E50 10-1-10	26	217	271	283	273	271	271	271	273	281	238	215	225	240	283	215
E50 10-2-1	35	179	254	255	254	255	255	255	254	255	202	198	203	205	255	179
E50 10-2-2	35	202	269	281	277	273	269	269	276	273	223	210	222	228	281	202
E50 10-2-3	20	190	239	239	239	239	239	239	239	239	201	204	209	197	239	190
E50 10-2-4	22	220	278	278	277	278	278	278	278	278	233	222	241	235	278	220
E50 10-2-5	22	173	227	227	227	227	227	227	227	227	184	178	186	193	227	173
E50 10-2-6	24	206	267	266	265	268	268	267	266	268	232	213	220	224	268	206
E50 10-2-7	24	210	266	267	265	267	266	266	266	267	221	213	217	216	267	210
E50 10-2-8	26	233	270	270	268	270	270	270	270	270	239	231	250	259	270	231
E50 10-2-9	32	228	300	300	300	300	300	300	295	300	254	233	229	249	300	228
E50 10-2-10	31	235	299	299	292	299	299	299	295	299	260	252	262	250	299	235
E50 10-3-1	28	213	307	305	309	309	307	309	309	309	247	227	227	241	309	213
E50 10-3-2	31	211	286	280	283	280	286	286	279	286	215	221	219	213	286	211
E50 10-3-3	42	230	303	303	303	303	303	303	303	303	238	247	232	230	303	230
E50 10-3-4	37	215	271	270	269	271	270	270	271	271	219	222	228	225	271	215

Table D.1 Minimum makespans for 50-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 10-3-5	40	208	286	278	278	277	286	286	285	286	223	212	221	212	286	208
E50 10-3-6	30	199	246	246	246	246	239	246	239	246	205	202	207	206	246	199
E50 10-3-7	32	203	257	257	257	257	257	257	257	257	218	207	213	218	257	203
E50 10-3-8	32	198	258	254	254	258	258	258	258	258	203	195	200	199	258	195
E50 10-3-9	31	209	279	280	279	280	280	279	279	280	224	235	219	224	287	209
E50 10-3-10	30	214	298	294	296	298	298	298	298	298	223	226	241	226	298	214
E50 10-4-1	32	207	278	278	278	278	275	278	275	278	220	209	221	219	275	207
E50 10-4-2	33	217	281	281	281	281	281	281	281	281	241	230	230	241	281	217
E50 10-4-3	35	206	281	281	281	281	281	281	276	281	235	214	228	224	281	206
E50 10-4-4	36	225	280	280	280	280	280	280	280	280	224	224	231	229	280	224
E50 10-4-5	33	193	273	276	266	270	267	264	267	268	216	197	205	207	276	193
E50 10-4-6	35	211	277	277	277	277	277	277	277	277	232	218	224	228	277	211
E50 10-4-7	36	216	274	278	274	274	274	274	274	274	229	212	219	219	278	212
E50 10-4-8	34	202	278	272	269	278	275	278	272	278	212	217	229	216	278	202
E50 10-4-9	42	239	290	290	290	290	290	290	290	290	247	243	238	244	290	238
E50 10-4-10	35	241	298	303	298	298	298	298	304	298	248	242	256	248	304	241
E50 15-1-1	27	207	267	267	267	267	267	267	267	267	225	209	223	227	267	207
E50 15-1-2	22	189	252	252	252	252	252	252	252	252	212	197	202	209	252	189
E50 15-1-3	22	195	260	260	260	260	260	260	260	260	223	202	202	216	260	195
E50 15-1-4	31	204	262	262	262	262	262	262	262	262	217	205	214	218	262	204
E50 15-1-5	33	216	269	269	269	269	269	269	269	269	232	225	226	234	269	216
E50 15-1-6	33	236	313	312	307	313	313	313	306	313	248	244	280	252	313	236
E50 15-1-7	33	226	285	285	284	285	285	285	285	285	249	234	233	244	285	226
E50 15-1-8	31	217	287	287	287	287	287	287	287	287	264	225	240	250	287	217
E50 15-1-9	38	237	293	293	288	293	293	293	293	293	249	225	247	254	293	225
E50 15-1-10	20	186	256	256	256	256	256	256	256	256	207	202	214	208	256	186
E50 15-2-1	29	204	261	261	261	261	261	261	261	261	233	212	214	239	261	204
E50 15-2-2	30	207	276	276	276	276	276	276	276	276	230	221	230	223	276	207
E50 15-2-3	24	207	288	288	286	288	288	288	288	288	233	219	235	219	288	207

Table D.1 Minimum makespans for 50-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E50 15-2-4	37	254	326	326	326	326	326	326	326	326	276	278	260	268	326	254
E50 15-2-5	26	216	270	270	270	270	270	270	270	270	223	207	221	216	270	207
E50 15-2-6	29	185	233	233	233	233	233	233	233	233	195	179	198	196	233	179
E50 15-2-7	31	207	296	296	296	296	296	296	296	296	234	216	233	233	296	207
E50 15-2-8	36	221	289	289	289	289	289	289	289	289	236	232	229	244	289	221
E50 15-2-9	26	230	274	274	273	274	274	273	273	274	236	234	235	241	274	230
E50 15-2-10	28	233	289	289	289	289	289	289	289	289	236	228	231	248	289	228
E50 15-3-1	32	209	267	264	264	267	267	267	264	267	219	201	212	218	267	201
E50 15-3-2	31	200	270	270	270	270	270	270	270	270	230	219	206	213	270	200
E50 15-3-3	34	211	298	298	298	298	298	298	298	298	237	220	236	221	298	211
E50 15-3-4	37	205	263	263	263	263	263	263	263	263	205	209	216	213	263	205
E50 15-3-5	34	193	267	267	267	267	267	267	267	267	201	204	204	202	267	193
E50 15-3-6	22	185	246	246	246	246	246	246	246	246	188	187	193	195	246	185
E50 15-3-7	31	199	268	268	267	268	268	268	268	268	201	204	210	205	268	199
E50 15-3-8	42	198	246	246	246	246	246	246	246	246	200	198	197	196	246	196
E50 15-3-9	27	184	247	247	247	247	247	247	247	247	192	186	201	192	247	184
E50 15-3-10	37	256	324	322	324	324	324	324	324	324	267	258	263	259	324	256
E50 15-4-1	20	217	278	278	278	278	278	278	278	278	229	225	239	239	278	217
E50 15-4-2	35	201	290	290	290	290	290	290	281	290	217	212	209	214	290	201
E50 15-4-3	31	217	277	277	277	277	277	277	277	277	233	209	207	205	277	205
E50 15-4-4	36	204	278	278	278	278	278	278	278	278	214	212	212	220	278	204
E50 15-4-5	34	210	280	280	273	280	280	280	273	280	229	228	219	228	280	210
E50 15-4-6	29	177	246	246	246	246	246	246	246	246	201	196	204	200	246	177
E50 15-4-7	33	231	297	297	297	297	297	297	297	297	247	230	249	240	297	230
E50 15-4-8	34	206	270	270	270	270	270	270	270	270	233	210	227	226	270	206
E50 15-4-9	24	198	273	273	273	273	273	273	273	273	217	205	216	216	273	198
E50 15-4-10	24	193	255	255	255	255	255	255	255	255	214	198	214	210	255	193

Table D.2 Minimum makespans for 100-activity instances

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-1-1-1	330	432	428	487	424	489	446	474	414	489	475	474	469	476	489	414
E100-1-1-2	399	475	460	484	468	489	479	477	450	495	480	480	495	480	504	450
E100-1-1-3	413	483	480	503	476	526	494	481	470	526	526	528	541	528	539	470
E100-1-1-4	324	400	405	449	403	465	436	440	366	465	437	433	462	443	490	366
E100-1-1-5	386	443	433	457	428	468	453	443	420	468	457	455	467	457	533	420
E100-1-1-6	327	449	429	463	424	461	443	441	419	461	441	442	454	459	488	419
E100-1-1-7	377	416	416	456	411	456	438	427	409	456	453	452	468	451	506	409
E100-1-1-8	387	447	455	468	441	483	466	484	439	483	488	487	492	490	500	439
E100-1-1-9	407	447	453	485	464	491	466	469	447	491	494	481	500	497	499	447
E100-1-1-10	391	449	448	482	444	488	470	460	429	488	479	466	499	482	501	429
E100-1-2-1	272	415	381	413	419	418	393	421	395	423	454	406	427	444	494	381
E100-1-2-2	248	408	390	416	407	418	400	393	384	418	427	399	419	423	461	384
E100-1-2-3	283	439	423	472	424	478	460	440	415	478	476	468	482	465	532	415
E100-1-2-4	249	448	414	446	410	462	431	419	420	462	485	468	481	475	510	410
E100-1-2-5	244	375	377	407	395	415	370	371	366	409	416	397	428	414	412	366
E100-1-2-6	252	442	404	442	411	442	418	410	405	442	470	435	480	463	511	404
E100-1-2-7	228	367	366	411	355	397	390	408	353	398	402	385	419	399	448	353
E100-1-2-8	282	394	406	407	406	422	398	406	388	422	439	410	436	437	469	388
E100-1-2-9	274	409	403	430	392	436	419	433	387	435	421	426	463	428	483	387
E100-1-2-10	263	381	380	417	387	414	395	405	370	416	431	414	437	432	497	370
E100-1-3-1	139	415	384	410	401	414	370	404	375	423	440	433	438	434	475	370
E100-1-3-2	126	393	353	379	366	381	341	379	343	385	424	423	439	426	472	341
E100-1-3-3	171	363	357	359	363	366	343	362	339	372	413	393	375	414	508	339
E100-1-3-4	142	375	370	392	394	405	362	413	358	403	417	405	434	419	531	358
E100-1-3-5	120	385	356	386	382	381	375	366	342	390	432	412	405	434	499	342

Table D.2 Minimum makespans for 100-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-1-3-6	156	375	366	386	351	400	347	370	355	405	435	402	423	430	589	347
E100-1-3-7	187	468	437	468	455	485	433	474	418	478	491	475	461	511	559	418
E100-1-3-8	186	415	389	428	400	432	390	436	379	433	473	440	456	458	522	379
E100-1-3-9	156	373	347	377	359	385	361	349	343	386	420	399	411	394	492	343
E100-1-3-10	130	332	319	334	324	385	326	361	308	362	377	384	366	409	435	308
E100-1-4-1	61	344	324	337	333	333	329	330	316	331	393	367	377	395	399	316
E100-1-4-2	58	395	331	339	341	361	333	351	324	371	451	408	421	402	515	324
E100-1-4-3	54	396	362	385	371	370	360	389	347	383	442	405	423	430	450	347
E100-1-4-4	54	385	352	359	359	379	348	364	347	374	433	401	407	435	458	347
E100-1-4-5	60	357	306	312	307	319	298	333	296	328	386	384	388	385	474	296
E100-1-4-6	65	406	342	354	354	369	329	353	326	361	432	410	420	454	457	326
E100-1-4-7	53	402	349	355	352	363	343	357	350	381	440	391	408	457	480	343
E100-1-4-8	57	410	369	367	336	390	351	358	336	377	422	425	436	441	501	336
E100-1-4-9	68	363	329	356	338	352	319	353	320	355	402	381	377	412	420	319
E100-1-4-10	63	340	294	306	299	308	290	311	281	305	365	343	364	373	431	281
E100-5-1-1	330	520	533	554	531	554	556	528	533	554	492	492	544	477	554	477
E100-5-1-2	381	492	515	515	515	515	515	515	515	515	505	507	510	500	500	492
E100-5-1-3	344	447	451	472	464	473	470	472	450	472	419	443	472	419	478	419
E100-5-1-4	404	550	538	576	533	576	571	559	544	576	486	537	571	487	574	486
E100-5-1-5	347	482	506	522	497	528	525	518	484	528	446	465	496	449	514	446
E100-5-1-6	400	534	530	541	524	552	545	534	521	552	476	499	551	481	547	476
E100-5-1-7	332	499	509	522	497	522	514	502	495	522	446	475	509	455	508	446
E100-5-1-8	357	539	532	559	530	562	549	541	514	562	502	486	546	496	548	486
E100-5-1-9	384	519	524	517	516	525	527	517	516	525	487	488	526	485	527	485
E100-5-1-10	403	517	542	543	537	545	540	550	542	543	522	528	542	516	547	516
E100-5-2-1	272	487	508	522	506	522	513	519	515	522	457	468	512	435	528	435
E100-5-2-2	246	463	509	540	510	540	528	512	512	540	468	474	490	447	550	447
E100-5-2-3	304	507	565	575	571	584	584	573	566	584	502	514	567	503	580	502
E100-5-2-4	279	500	539	553	548	561	554	543	541	561	454	490	535	460	562	454

Table D.2 Minimum makespans for 100-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-5-2-5	259	464	491	516	496	523	520	489	495	523	428	455	509	430	533	428
E100-5-2-6	258	500	555	565	536	565	563	553	550	565	458	508	553	485	565	458
E100-5-2-7	277	495	514	540	541	537	536	521	524	537	451	471	543	444	554	444
E100-5-2-8	244	496	505	533	510	533	525	519	507	533	456	478	517	447	530	447
E100-5-2-9	311	543	567	578	567	584	576	578	563	578	499	519	579	492	583	492
E100-5-2-10	239	500	496	515	502	518	497	507	506	518	431	465	499	421	509	421
E100-5-3-1	139	395	496	520	520	519	504	522	486	526	414	418	431	412	530	395
E100-5-3-2	120	435	500	512	503	520	516	501	517	526	453	445	465	455	557	435
E100-5-3-3	173	417	516	540	532	524	523	532	530	528	442	454	489	456	553	417
E100-5-3-4	159	418	480	499	475	499	474	487	473	499	402	410	463	403	495	402
E100-5-3-5	161	438	481	519	495	532	494	513	475	532	416	423	443	415	511	415
E100-5-3-6	140	392	492	510	492	482	486	489	492	492	406	417	423	411	507	392
E100-5-3-7	156	455	525	536	518	545	523	532	526	540	449	454	472	432	557	432
E100-5-3-8	158	419	505	509	506	522	505	522	490	520	410	427	474	422	534	410
E100-5-3-9	199	459	520	543	521	548	536	539	514	551	430	474	504	442	546	430
E100-5-3-10	147	415	496	508	513	520	502	529	488	522	429	431	456	424	507	415
E100-5-4-1	61	344	454	453	450	472	445	467	448	464	385	368	365	373	496	344
E100-5-4-2	55	351	439	451	421	459	435	447	443	458	369	356	363	357	504	351
E100-5-4-3	56	382	474	500	481	510	482	494	464	505	381	393	415	396	547	381
E100-5-4-4	61	394	499	500	498	508	487	494	481	507	396	398	398	413	524	394
E100-5-4-5	66	443	520	533	529	549	518	522	501	554	477	462	470	475	575	443
E100-5-4-6	59	319	424	444	431	458	430	427	405	442	340	347	355	349	452	319
E100-5-4-7	67	395	510	495	509	516	491	518	465	529	443	411	416	445	575	395
E100-5-4-8	60	374	513	522	503	549	521	543	490	535	400	422	419	419	560	374
E100-5-4-9	55	410	451	569	548	550	541	571	534	573	453	449	437	428	586	410
E100-5-4-10	52	401	504	522	502	530	490	519	491	545	403	409	408	413	536	401
E100-10-1-1	330	513	540	545	535	558	555	557	535	558	497	497	531	480	558	480
E100-10-1-2	370	519	534	541	534	541	541	541	534	541	496	509	538	490	541	490
E100-10-1-3	400	566	582	574	574	582	582	582	574	582	548	548	582	537	582	537

Table D.2 Minimum makespans for 100-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-10-1-4	340	519	536	536	536	536	536	536	536	536	505	505	535	498	536	498
E100-10-1-5	399	538	552	563	534	563	558	562	542	563	492	513	563	495	563	492
E100-10-1-6	335	501	511	522	504	522	522	511	502	522	479	483	509	470	522	470
E100-10-1-7	338	509	538	538	522	538	538	529	536	538	476	480	529	467	538	467
E100-10-1-8	351	499	503	509	509	503	503	503	509	503	500	498	498	492	503	492
E100-10-1-9	358	477	504	509	497	509	504	505	497	509	447	468	500	454	509	447
E100-10-1-10	367	552	584	578	566	587	587	587	566	587	514	542	567	517	587	514
E100-10-2-1	272	507	525	524	521	528	528	525	521	528	476	465	523	448	528	448
E100-10-2-2	283	490	514	517	517	517	517	517	514	517	444	451	504	439	517	439
E100-10-2-3	253	501	529	529	523	529	529	529	529	529	461	474	461	452	529	452
E100-10-2-4	266	503	523	523	523	523	523	523	523	523	444	461	518	449	523	444
E100-10-2-5	293	549	592	596	595	596	593	592	592	596	547	540	582	530	596	530
E100-10-2-6	278	487	517	517	517	517	517	517	517	517	451	461	451	447	517	447
E100-10-2-7	265	517	569	569	566	569	569	569	566	569	467	489	539	468	569	467
E100-10-2-8	285	534	567	567	567	567	567	565	567	567	501	493	562	487	567	487
E100-10-2-9	262	468	499	502	499	502	502	499	499	502	423	437	500	417	502	417
E100-10-2-10	139	446	533	536	536	536	536	536	525	536	443	420	477	422	536	420
E100-10-3-1	144	459	557	558	543	558	558	558	548	558	446	449	494	466	558	446
E100-10-3-2	154	393	452	452	452	452	452	452	452	452	362	360	385	377	452	360
E100-10-3-3	126	400	479	481	481	481	479	481	472	481	376	369	429	362	481	362
E100-10-3-4	136	450	554	557	542	558	554	558	554	558	428	437	450	414	558	414
E100-10-3-5	173	443	525	525	525	525	525	525	525	525	447	428	490	438	525	428
E100-10-3-6	142	431	525	519	525	525	519	525	525	525	412	411	454	388	525	388
E100-10-3-7	161	472	529	531	531	531	529	531	529	531	471	454	495	443	531	443
E100-10-3-8	139	442	521	521	521	521	521	521	521	521	425	418	456	424	521	418
E100-10-3-9	123	406	507	509	501	509	509	509	509	509	407	395	446	407	509	395
E100-10-3-10	61	368	491	488	494	498	488	486	488	498	386	362	392	394	498	362
E100-10-4-1	75	403	517	518	518	518	518	518	517	518	424	402	408	413	518	402
E100-10-4-2	64	415	564	555	558	564	564	559	558	564	454	416	425	439	564	415

Table D.2 Minimum makespans for 100-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-10-4-3	64	375	523	528	528	535	534	535	523	535	396	389	398	389	535	375
E100-10-4-4	46	373	504	503	504	504	504	504	504	504	394	380	381	381	504	373
E100-10-4-5	60	374	524	526	523	524	520	525	517	524	391	374	389	387	524	374
E100-10-4-6	253	501	529	529	523	529	529	529	529	529	461	474	461	452	529	452
E100-10-4-7	48	431	584	590	590	590	584	590	584	590	465	438	461	476	590	431
E100-10-4-8	62	415	539	565	557	565	544	556	539	557	449	420	442	448	557	415
E100-10-4-9	44	355	477	485	487	485	475	477	477	485	393	384	393	392	485	355
E100-10-4-10	58	385	513	513	513	513	513	513	513	513	398	398	403	408	513	385
E100-15-1-1	330	525	557	558	542	558	558	551	551	558	498	478	539	483	558	478
E100-15-1-2	344	506	499	511	501	511	511	511	499	511	483	489	511	479	511	479
E100-15-1-3	391	554	562	562	562	562	562	562	562	562	524	523	559	519	562	519
E100-15-1-4	383	553	559	550	531	559	559	543	549	559	516	524	551	514	559	514
E100-15-1-5	390	553	544	552	535	552	552	544	535	552	520	525	552	502	552	502
E100-15-1-6	408	541	552	546	546	552	552	552	546	552	505	519	552	507	552	505
E100-15-1-7	351	501	508	508	499	508	508	506	499	508	457	470	503	458	508	457
E100-15-1-8	386	524	543	543	543	543	543	543	543	543	500	498	538	491	543	491
E100-15-1-9	357	557	574	574	569	574	574	574	574	574	527	529	553	527	574	527
E100-15-1-10	373	530	553	553	550	553	553	550	550	553	537	529	541	531	553	529
E100-15-2-1	272	515	528	528	528	528	528	528	528	528	459	459	524	463	528	459
E100-15-2-2	307	577	612	612	612	612	612	612	612	612	537	537	604	537	612	537
E100-15-2-3	314	560	589	589	589	589	589	589	589	589	563	563	580	550	589	550
E100-15-2-4	247	502	529	529	520	529	529	529	520	529	469	463	509	462	529	462
E100-15-2-5	283	510	525	525	525	525	525	525	525	525	492	489	525	481	525	481
E100-15-2-6	234	488	517	517	515	517	517	517	515	517	445	453	505	442	517	442
E100-15-2-7	284	553	581	581	573	581	581	581	573	581	496	507	568	507	581	496
E100-15-2-8	285	543	588	588	588	588	588	588	588	588	529	524	557	517	588	517
E100-15-2-9	269	569	592	586	591	592	592	592	592	592	482	504	583	489	592	482
E100-15-2-10	273	518	553	553	553	553	553	553	553	553	491	481	540	486	553	481
E100-15-3-1	139	449	536	536	536	536	536	536	536	536	429	427	493	433	536	427

Table D.2 Minimum makespans for 100-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E100-15-3-2	169	500	585	585	585	585	585	585	585	585	485	465	527	491	585	465
E100-15-3-3	176	499	589	589	589	589	589	589	589	589	501	460	536	536	589	460
E100-15-3-4	149	390	484	484	484	484	484	484	484	484	403	405	434	406	484	390
E100-15-3-5	132	473	587	587	579	587	587	587	587	587	465	445	500	465	587	445
E100-15-3-6	133	442	514	514	514	514	514	514	514	514	429	420	457	425	514	420
E100-15-3-7	165	491	574	574	574	574	574	574	574	574	475	477	514	469	574	469
E100-15-3-8	133	414	497	497	497	497	497	497	497	497	418	398	444	419	497	398
E100-15-3-9	123	454	538	538	536	538	538	538	536	538	441	412	490	439	538	412
E100-15-3-10	126	470	554	554	546	554	554	554	554	554	455	441	488	440	554	440
E100-15-4-1	61	347	498	493	498	498	498	498	493	498	413	380	383	386	498	347
E100-15-4-2	75	440	603	603	603	603	603	603	603	603	424	450	473	476	603	424
E100-15-4-3	73	387	558	558	552	558	558	558	558	558	389	404	427	436	558	387
E100-15-4-4	49	376	525	525	519	525	525	525	525	525	427	411	420	419	525	376
E100-15-4-5	62	479	604	604	604	604	604	604	604	604	502	481	505	497	604	479
E100-15-4-6	61	405	577	577	577	577	577	577	577	577	444	418	436	429	577	405
E100-15-4-7	50	460	583	583	583	583	583	583	583	583	456	460	467	471	583	456
E100-15-4-8	76	425	553	553	553	553	553	553	548	553	421	427	420	430	553	420
E100-15-4-9	71	415	572	572	572	572	572	572	572	572	428	426	447	437	572	415
E100-15-4-10	63	381	505	508	508	508	508	508	505	508	404	383	382	393	508	381

Table D.3 Minimum makespans for 200-activity instances

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-1-1-1	780	1188	1192	1196	1192	1196	1196	1184	1184	1196	1196	1192	1189	1198	1196	1184
E200-1-1-2	775	1137	1137	1137	1137	1137	1137	1137	1137	1137	1137	1137	1137	1137	1137	1137
E200-1-1-3	787	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
E200-1-1-4	733	1045	1048	1053	1044	1056	1053	1048	1047	1053	1053	1053	1047	1053	1056	1044
E200-1-1-5	782	1061	1065	1065	1065	1065	1065	1065	1061	1065	1061	1065	1065	1061	1065	1061
E200-1-1-6	779	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
E200-1-1-7	743	1075	1078	1078	1078	1078	1078	1078	1078	1078	1078	1078	1078	1078	1078	1075
E200-1-1-8	763	1095	1086	1095	1086	1095	1095	1095	1086	1095	1091	1089	1095	1085	1095	1085
E200-1-1-9	771	1099	1099	1102	1095	1102	1102	1095	1095	1102	1098	1121	1109	1098	1102	1095
E200-1-1-10	774	1082	1079	1082	1079	1082	1082	1079	1079	1082	1079	1079	1082	1079	1073	1073
E200-1-2-1	560	860	832	909	835	916	851	845	808	917	907	877	931	904	1055	808
E200-1-2-2	544	754	779	801	770	809	769	785	757	803	855	831	841	832	946	754
E200-1-2-3	563	837	821	938	862	948	837	878	817	950	916	899	953	928	878	817
E200-1-2-4	528	810	778	867	796	866	811	823	785	864	853	864	879	863	823	778
E200-1-2-5	525	816	804	863	826	854	851	839	798	853	874	850	882	873	839	798
E200-1-2-6	501	777	744	860	786	847	776	781	718	851	845	822	883	838	781	718
E200-1-2-7	571	812	807	857	827	867	785	847	805	859	891	871	885	876	847	785
E200-1-2-8	611	968	964	998	990	1008	955	1008	955	997	1079	1048	1071	1062	1008	955
E200-1-2-9	569	882	883	934	922	942	879	928	880	939	947	942	984	933	934	879
E200-1-2-10	568	846	838	919	862	921	866	888	842	927	974	921	940	943	919	838
E200-1-3-1	316	758	733	770	741	818	736	784	710	815	832	806	840	839	770	710
E200-1-3-2	341	751	701	747	704	756	707	741	685	765	834	784	809	817	747	685
E200-1-3-3	368	764	777	830	772	844	753	814	756	837	851	818	827	858	830	753
E200-1-3-4	344	759	703	780	738	791	721	766	688	808	811	821	815	827	780	688
E200-1-3-5	339	736	699	745	734	759	695	747	668	752	800	775	820	781	745	668

Table D.3 Minimum makespans for 200-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-1-3-6	373	797	735	813	761	799	745	789	738	800	866	840	839	858	813	735
E200-1-3-7	305	726	685	750	709	774	698	756	656	772	826	775	818	814	750	656
E200-1-3-8	392	793	762	812	791	834	767	834	760	823	872	842	864	873	812	760
E200-1-3-9	337	769	727	740	737	762	710	764	711	755	866	798	836	848	740	710
E200-1-3-10	326	847	778	807	784	818	785	830	771	834	906	848	874	891	807	771
E200-1-4-1	124	837	743	756	764	798	732	769	729	796	899	842	849	908	756	729
E200-1-4-2	107	741	657	697	694	712	658	699	636	717	816	768	772	819	697	636
E200-1-4-3	112	700	619	663	643	691	628	681	603	696	756	738	737	746	663	603
E200-1-4-4	127	701	606	654	617	679	604	621	578	657	726	704	735	735	654	578
E200-1-4-5	124	763	682	722	698	762	675	699	673	733	833	751	791	819	722	673
E200-1-4-6	109	840	730	771	779	774	716	763	724	787	909	833	854	917	771	716
E200-1-4-7	122	778	699	739	703	778	670	725	669	742	782	791	793	853	739	669
E200-1-4-8	135	820	700	721	706	741	686	725	702	743	826	817	824	850	721	686
E200-1-4-9	117	734	646	672	662	714	638	690	621	703	785	756	775	794	672	621
E200-1-4-10	140	844	745	772	776	781	728	812	734	794	877	866	877	897	772	728
E200-5-1-1	799	1121	1183	1181	1179	1187	1176	1178	1160	1187	1088	1092	1175	1105	1189	1088
E200-5-1-2	794	1067	1109	1110	1079	1123	1115	1121	1080	1123	1018	1058	1114	1030	1127	1018
E200-5-1-3	787	1063	1067	1087	1052	1087	1084	1079	1044	1087	1030	1049	1092	1019	1094	1019
E200-5-1-4	733	1008	1040	1046	1026	1046	1045	1046	1029	1046	1000	1019	1046	1000	1046	1000
E200-5-1-5	782	995	1054	1048	1033	1053	1057	1044	1021	1053	955	989	1051	951	1065	951
E200-5-1-6	779	1030	1056	1091	1077	1083	1074	1084	1049	1094	1035	1015	1094	1026	1098	1015
E200-5-1-7	743	1043	1043	1060	1031	1071	1058	1045	1024	1066	994	1011	1066	983	1067	983
E200-5-1-8	763	1019	1068	1063	1047	1071	1069	1044	1046	1071	991	1029	1071	983	1095	983
E200-5-1-9	771	1051	1091	1097	1088	1097	1090	1088	1083	1097	1021	1047	1095	1095	1102	1021
E200-5-1-10	774	1038	1077	1082	1060	1082	1077	1077	1066	1082	1009	1022	1082	1007	1066	1007
E200-5-2-1	560	949	1004	1023	1013	1021	1001	1020	993	1022	868	918	1002	874	1029	868
E200-5-2-2	564	974	1041	1067	1045	1054	1039	1063	1040	1054	959	972	1042	954	1091	954
E200-5-2-3	523	920	977	975	970	980	966	961	963	981	912	905	940	907	997	905
E200-5-2-4	557	939	1021	1043	1036	1039	1034	1042	1018	1035	862	934	995	868	1053	862

Table D.3 Minimum makespans for 200-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-5-2-5	575	932	1034	1053	1042	1047	1033	1052	1042	1048	980	983	1019	961	1048	932
E200-5-2-6	562	1004	1061	1096	1074	1098	1074	1056	1052	1091	918	948	1037	917	1123	917
E200-5-2-7	591	1022	1057	1076	1060	1073	1056	1067	1061	1073	1023	1023	1052	1000	1074	1000
E200-5-2-8	556	919	1013	1022	1020	1029	1015	1024	1007	1035	948	943	965	940	1043	919
E200-5-2-9	532	972	1057	1072	1062	1073	1066	1069	1048	1074	930	979	1050	904	1091	904
E200-5-2-10	528	988	1034	1086	1055	1081	1055	1063	1034	1072	913	948	1034	900	1092	900
E200-5-3-1	316	876	1019	1048	1025	1055	1014	1052	1019	1067	890	869	929	839	1064	839
E200-5-3-2	395	867	959	986	974	996	960	1000	964	1004	879	869	919	879	1032	867
E200-5-3-3	365	909	1006	1047	1016	1048	1025	1059	1003	1051	858	904	953	857	1051	857
E200-5-3-4	338	851	1013	1026	988	1028	1010	1002	993	1044	889	893	939	875	1044	851
E200-5-3-5	406	923	1029	1053	1028	1046	1023	1053	1040	1044	937	940	967	937	1044	923
E200-5-3-6	322	886	1001	1049	1026	1059	1033	1049	995	1070	883	878	932	864	1070	864
E200-5-3-7	314	835	964	1001	965	997	957	979	940	995	872	856	892	837	995	835
E200-5-3-8	333	878	1015	1068	1033	1073	1037	1044	1010	1064	854	875	935	861	1064	854
E200-5-3-9	358	881	1046	1071	1026	1073	1036	1065	1039	1060	867	879	951	866	1060	866
E200-5-3-10	353	906	1051	1119	1053	1092	1081	1079	1046	1092	927	926	1001	929	1092	906
E200-5-4-1	124	735	961	1001	1014	1007	974	1015	939	1018	790	770	742	781	1018	735
E200-5-4-2	108	739	954	1022	977	1015	965	982	948	997	793	784	781	795	997	739
E200-5-4-3	112	744	955	1004	955	1004	955	1004	939	993	795	775	751	790	993	744
E200-5-4-4	135	838	1068	1071	1082	1117	1057	1086	1020	1096	888	885	849	866	1096	838
E200-5-4-5	110	739	963	983	948	997	925	983	921	1002	777	759	783	764	1002	739
E200-5-4-6	126	794	1027	1056	1039	1064	1023	1055	1019	1051	832	821	832	829	1051	794
E200-5-4-7	130	752	1006	1016	1011	1047	995	1004	980	1027	797	799	769	801	1027	752
E200-5-4-8	127	744	1008	1064	1005	1066	986	1045	961	1069	795	790	773	782	1069	744
E200-5-4-9	117	794	1000	1028	1039	1060	1044	1059	998	1054	850	830	837	836	1054	794
E200-5-4-10	125	722	957	982	987	1021	957	1004	935	1020	767	773	744	757	1020	722
E200-10-1-1	874	1170	1196	1196	1187	1196	1196	1196	1187	1196	1143	1169	1187	1138	1196	1138
E200-10-1-2	748	1014	1037	1037	1030	1030	1037	1037	1030	1037	980	989	1037	967	1037	967
E200-10-1-3	815	1105	1140	1143	1140	1143	1143	1140	1140	1143	1118	1100	1143	1090	1143	1090

Table D.3 Minimum makespans for 200-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-10-1-4	730	1033	1044	1044	1044	1044	1039	1044	1044	1044	1013	1010	1040	1003	1044	1003
E200-10-1-5	831	1099	1105	1110	1095	1110	1107	1102	1095	1110	1040	1062	1110	1027	1110	1027
E200-10-1-6	785	1086	1118	1113	1118	1113	1108	1113	1118	1113	1087	1067	1113	1071	1113	1067
E200-10-1-7	754	1063	1079	1079	1061	1079	1079	1079	1057	1079	1024	1024	1079	1029	1079	1024
E200-10-1-8	779	1072	1102	1104	1083	1104	1104	1102	1083	1104	1051	1069	1104	1039	1104	1039
E200-10-1-9	728	1039	1046	1048	1046	1048	1048	1046	1041	1048	1005	1005	1048	993	1048	993
E200-10-1-10	820	1126	1144	1144	1129	1144	1144	1137	1129	1144	1093	1105	1144	1091	1144	1091
E200-10-2-1	560	986	1046	1055	1046	1055	1053	1043	1043	1055	960	958	1018	959	1055	958
E200-10-2-2	539	963	1045	1043	1043	1045	1037	1043	1042	1045	935	937	994	920	1045	920
E200-10-2-3	534	961	1030	1041	1033	1041	1033	1033	1038	1041	917	950	1018	921	1041	917
E200-10-2-4	561	1027	1089	1099	1089	1099	1097	1089	1089	1099	944	971	944	935	1099	935
E200-10-2-5	575	989	1058	1058	1058	1058	1058	1058	1058	1058	977	980	1019	962	1058	962
E200-10-2-6	922	991	1072	1072	1071	1072	1072	1071	1071	1072	920	968	1040	922	1072	920
E200-10-2-7	556	998	1077	1078	1070	1078	1080	1080	1070	1078	948	993	1063	949	1078	948
E200-10-2-8	576	969	1092	1092	1096	1092	1092	1096	1092	1092	998	988	1049	992	1092	969
E200-10-2-9	495	990	1059	1062	1058	1062	1062	1057	1051	1062	915	931	1034	889	1062	889
E200-10-2-10	545	1023	1111	1111	1111	1111	1103	1111	1111	1111	968	988	1078	971	1111	968
E200-10-3-1	316	896	1071	1075	1072	1082	1080	1081	1073	1082	867	887	939	857	1082	857
E200-10-3-2	333	911	1030	1041	1024	1041	1041	1041	1024	1041	867	882	966	865	1041	865
E200-10-3-3	331	929	1104	1104	1104	1104	1102	1104	1104	1104	948	932	995	914	1104	914
E200-10-3-4	336	927	1053	1058	1053	1058	1058	1059	1052	1052	914	897	966	893	1052	893
E200-10-3-5	375	953	1083	1083	1092	1083	1077	1092	1083	1083	948	932	1013	932	1083	932
E200-10-3-6	373	898	1081	1089	1080	1093	1083	1076	1080	1093	934	909	990	903	1093	898
E200-10-3-7	340	973	1090	1092	1091	1092	1089	1092	1089	1092	916	909	1001	908	1092	908
E200-10-3-8	836	891	1035	1044	1023	1044	1035	1029	1016	1048	836	844	959	851	1048	836
E200-10-3-9	383	976	1153	1157	1130	1157	1157	1157	1126	1157	970	966	1070	955	1157	955
E200-10-3-10	344	973	1112	1121	1121	1121	1121	1121	1112	1121	962	935	1051	948	1121	935
E200-10-4-1	124	758	1084	1091	1079	1094	1080	1082	1075	1089	815	775	778	782	1089	758
E200-10-4-2	121	795	1077	1082	1086	1082	1076	1078	1079	1082	818	802	818	806	1082	795

Table D.3 Minimum makespans for 200-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-10-4-3	816	800	1054	1065	1056	1071	1068	1072	1056	1077	821	803	811	816	1077	800
E200-10-4-4	123	812	1134	1139	1136	1139	1137	1136	1137	1136	841	820	822	845	1136	812
E200-10-4-5	803	785	1052	1061	1053	1064	1036	1048	1047	1058	805	786	799	803	1058	785
E200-10-4-6	114	817	1106	1106	1106	1105	1099	1106	1099	1106	836	807	828	846	1106	807
E200-10-4-7	115	754	1025	1025	1028	1033	1020	1033	1018	1033	760	743	760	768	1033	743
E200-10-4-8	129	815	1111	1115	1118	1120	1117	1112	1103	1117	827	812	857	825	1130	812
E200-10-4-9	123	789	1063	1062	1061	1076	1077	1073	1048	1072	806	772	817	784	1081	772
E200-10-4-10	121	786	1071	1082	1081	1076	1072	1082	1067	1082	844	785	831	809	1082	785
E200-15-1-1	874	1176	1196	1196	1186	1196	1196	1196	1186	1196	1155	1164	1196	1149	1196	1149
E200-15-1-2	805	1113	1132	1132	1125	1132	1132	1132	1125	1132	1068	1085	1132	1069	1132	1068
E200-15-1-3	791	1095	1116	1116	1111	1116	1116	1116	1111	1116	1061	1082	1116	1061	1116	1061
E200-15-1-4	769	1102	1112	1112	1112	1112	1112	1112	1112	1112	1087	1085	1112	1077	1112	1077
E200-15-1-5	786	1109	1117	1117	1117	1117	1117	1117	1117	1117	1092	1100	1111	1070	1117	1070
E200-15-1-6	800	1119	1135	1135	1123	1135	1135	1135	1123	1135	1099	1089	1135	1103	1135	1089
E200-15-1-7	782	1100	1126	1126	1126	1126	1126	1126	1126	1126	1076	1076	1122	1078	1126	1076
E200-15-1-8	807	1121	1130	1130	1122	1130	1130	1130	1122	1130	1094	1098	1130	1086	1130	1086
E200-15-1-9	768	1085	1105	1105	1105	1105	1105	1105	1105	1105	1057	1061	1105	1062	1105	1057
E200-15-1-10	795	1090	1101	1101	1096	1101	1101	1101	1096	1101	1070	1072	1101	1063	1101	1063
E200-15-2-1	560	976	1055	1055	1055	1055	1055	1055	1055	1055	951	952	1035	936	1055	936
E200-15-2-2	569	1132	1170	1170	1163	1170	1170	1170	1155	1170	1005	1107	1120	1016	1170	1005
E200-15-2-3	541	1053	1116	1116	1108	1116	1116	1116	1108	1116	949	975	1091	962	1116	949
E200-15-2-4	567	1060	1127	1127	1127	1127	1127	1127	1127	1127	969	974	1089	955	1127	955
E200-15-2-5	532	1053	1108	1108	1090	1108	1108	1108	1099	1108	975	999	1087	950	1108	950
E200-15-2-6	558	1022	1101	1101	1101	1101	1101	1101	1101	1101	974	985	1068	987	1101	974
E200-15-2-7	598	1066	1136	1136	1136	1136	1136	1136	1136	1136	1020	1017	1092	1024	1136	1017
E200-15-2-8	543	1014	1080	1080	1080	1080	1080	1080	1080	1080	937	984	1050	940	1080	937
E200-15-2-9	563	1115	1180	1180	1175	1180	1180	1180	1175	1180	1023	1005	1083	1013	1180	1005
E200-15-2-10	582	1099	1150	1150	1150	1150	1150	1150	1150	1150	1025	1027	1127	1012	1150	1012
E200-15-3-1	316	914	1086	1086	1086	1086	1086	1086	1086	1086	1045	1019	1060	1015	1086	914

Table D.3 Minimum makespans for 200-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E200-15-3-2	401	979	1054	1054	1054	1054	1054	1054	1054	1054	1024	1025	1050	1030	1054	979
E200-15-3-3	374	926	1034	1034	1034	1034	1034	1034	1034	1034	1005	1010	1024	1002	1034	926
E200-15-3-4	356	922	1065	1065	1065	1065	1065	1065	1065	1065	953	925	982	957	1065	922
E200-15-3-5	319	952	1116	1116	1116	1116	1116	1116	1116	1116	954	933	990	935	1116	933
E200-15-3-6	335	889	1040	1040	1040	1040	1040	1040	1040	1040	871	865	938	842	1040	842
E200-15-3-7	341	954	1090	1096	1074	1096	1096	1086	1083	1096	882	896	1003	881	1096	881
E200-15-3-8	352	967	1126	1129	1122	1129	1129	1129	1126	1129	890	934	1022	929	1129	890
E200-15-3-9	383	956	1074	1079	1074	1079	1074	1079	1074	1079	930	913	974	928	1079	913
E200-15-3-10	358	1034	1165	1165	1165	1165	1165	1165	1165	1165	1024	1006	1083	1014	1165	1006
E200-15-4-1	124	817	1094	1094	1094	1094	1094	1094	1094	1094	838	791	820	826	1094	791
E200-15-4-2	126	761	1047	1051	1051	1051	1047	1046	1047	1051	791	760	788	808	1051	760
E200-15-4-3	122	829	1144	1145	1145	1145	1145	1145	1145	1145	845	813	837	861	1145	813
E200-15-4-4	104	789	1069	1073	1071	1073	1069	1073	1073	1073	827	804	796	815	1073	789
E200-15-4-5	134	784	1065	1065	1065	1065	1065	1065	1065	1065	824	773	803	773	1065	773
E200-15-4-6	121	781	1096	1096	1089	1096	1096	1096	1096	1096	798	796	808	815	1096	781
E200-15-4-7	126	801	1075	1075	1075	1075	1075	1075	1075	1075	810	814	801	827	1075	801
E200-15-4-8	117	764	1049	1047	1047	1049	1046	1049	1046	1049	809	758	796	795	1049	758
E200-15-4-9	131	793	1079	1076	1076	1076	1076	1070	1070	1076	833	772	812	822	1076	772
E200-15-4-10	100	774	1069	1069	1066	1069	1069	1069	1069	1069	805	779	794	807	1069	774

Table D.4 Minimum makespans for 500-activity instances

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 1-1-1	1862	2300	2300	2347	2270	2392	2306	2317	2249	2382	2320	2325	2384	2301	2347	2249
E500 1-1-2	1994	2389	2433	2425	2355	2448	2412	2433	2358	2459	2413	2398	2473	2407	2425	2355
E500 1-1-3	2027	2471	2466	2560	2489	2563	2478	2505	2461	2561	2505	2494	2597	2487	2560	2461
E500 1-1-4	1972	2363	2374	2467	2356	2485	2402	2411	2323	2489	2384	2372	2512	2372	2467	2323
E500 1-1-5	1866	2308	2311	2400	2304	2431	2328	2325	2276	2424	2340	2346	2421	2314	2400	2276
E500 1-1-6	2091	2524	2510	2521	2508	2515	2499	2519	2505	2509	2543	2534	2578	2527	2521	2499
E500 1-1-7	1898	2249	2239	2350	2208	2379	2248	2230	2211	2363	2238	2253	2360	2243	2350	2208
E500 1-1-8	1975	2372	2386	2447	2384	2475	2416	2422	2359	2476	2422	2416	2499	2425	2447	2359
E500 1-1-9	1870	2289	2307	2307	2265	2361	2293	2331	2235	2360	2296	2271	2365	2298	2307	2235
E500 1-1-10	2015	2311	2334	2380	2315	2401	2326	2368	2306	2402	2346	2364	2419	2337	2380	2306
E500 1-2-1	1382	2148	2092	2200	2136	2206	2098	2115	2058	2195	2155	2150	2236	2153	2200	2058
E500 1-2-2	1390	2104	2038	2218	2047	2234	2084	2083	1998	2234	2209	2155	2284	2160	2218	1998
E500 1-2-3	1346	2003	1977	2168	1983	2202	1999	2032	1924	2199	2049	2053	2196	2068	2168	1924
E500 1-2-4	1419	2188	2174	2307	2146	2318	2173	2208	2125	2303	2241	2231	2376	2211	2307	2125
E500 1-2-5	1469	2095	2059	2137	2093	2197	2073	2113	2025	2183	2165	2117	2249	2139	2137	2025
E500 1-2-6	1438	2232	2190	2308	2157	2344	2208	2216	2151	2325	2280	2269	2391	2259	2308	2151
E500 1-2-7	1476	2270	2212	2269	2205	2298	2229	2237	2198	2309	2320	2293	2388	2287	2269	2198
E500 1-2-8	1447	2175	2151	2264	2150	2281	2163	2215	2108	2265	2251	2208	2317	2222	2264	2108
E500 1-2-9	1441	2216	2172	2277	2154	2262	2174	2214	2098	2258	2232	2274	2341	2214	2277	2098
E500 1-2-10	1520	2274	2259	2369	2287	2392	2279	2295	2227	2380	2346	2343	2452	2333	2369	2227
E500 1-3-1	860	1926	1816	1977	1868	2034	1848	1971	1801	2032	2021	2082	2082	2020	1977	1801
E500 1-3-2	892	2091	1988	2163	2043	2210	1991	2116	1965	2193	2182	2106	2159	2165	2163	1965
E500 1-3-3	872	1997	1854	2005	1953	2028	1866	2006	1857	2044	2154	2083	2127	2101	2005	1854
E500 1-3-4	834	2021	1880	2094	1988	2129	1952	2041	1881	2130	2145	2084	2211	2088	2094	1880
E500 1-3-5	931	1928	1885	2031	1904	2079	1893	2009	1832	2062	2053	2022	2110	2024	2031	1832

Table D.4 Minimum makespans for 500-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 1-3-6	865	1906	1817	1913	1829	1990	1839	1945	1778	1978	1984	1971	2010	1941	1913	1778
E500 1-3-7	866	2093	2009	2143	2050	2164	2027	2132	1992	2161	2222	2140	2238	2206	2143	1992
E500 1-3-8	831	2068	1900	2082	1967	2110	1918	2024	1883	2113	2119	2081	2160	2094	2082	1883
E500 1-3-9	877	1965	1898	2047	1936	2082	1925	2019	1871	2107	2089	2045	2142	2088	2047	1871
E500 1-3-10	926	2030	1907	2026	1982	2096	1911	2046	1880	2069	2101	2052	2100	2050	2026	1880
E500 1-4-1	311	2029	1748	1899	1868	1908	1760	1894	1751	1926	2151	2064	2057	2150	1899	1748
E500 1-4-2	331	2097	1792	1969	1912	1993	1818	1933	1805	2011	2201	2128	2145	2203	1969	1792
E500 1-4-3	302	2027	1752	1900	1796	1928	1770	1886	1729	1920	2098	2016	2039	2110	1900	1729
E500 1-4-4	306	2026	1776	1955	1882	1981	1773	1921	1756	1947	2182	2071	2078	2152	1955	1756
E500 1-4-5	305	1954	1733	1861	1771	1885	1742	1837	1698	1921	2114	2034	2046	2117	1861	1698
E500 1-4-6	332	1987	1765	1903	1800	1914	1728	1875	1722	1893	2080	2032	2024	2111	1903	1722
E500 1-4-7	332	2017	1767	1936	1872	1950	1792	1905	1748	1971	2126	2060	2082	2147	1936	1748
E500 1-4-8	323	1945	1678	1845	1756	1854	1685	1801	1675	1848	2077	1970	1953	2047	1845	1675
E500 1-4-9	306	2060	1758	1934	1885	1969	1799	1965	1765	1956	2131	2068	2078	2155	1934	1758
E500 1-4-10	319	2026	1787	1924	1897	1964	1770	1915	1771	1944	2147	2064	2085	2140	1924	1770
E500 5-1-1	1862	2642	2654	2678	2577	2678	2661	2667	2569	2679	2500	2536	2611	2505	2577	2500
E500 5-1-2	1960	2614	2759	2797	2743	2812	2784	2798	2723	2814	2542	2617	2756	2543	2743	2542
E500 5-1-3	1899	2556	2648	2689	2616	2690	2665	2654	2613	2689	2492	2530	2629	2499	2616	2492
E500 5-1-4	1987	2574	2650	2649	2639	2669	2647	2668	2641	2671	2554	2587	2622	2545	2639	2545
E500 5-1-5	1836	2474	2607	2632	2581	2626	2611	2607	2564	2642	2353	2426	2587	2358	2581	2353
E500 5-1-6	1996	2580	2636	2658	2568	2658	2638	2639	2562	2654	2568	2590	2637	2558	2568	2558
E500 5-1-7	2043	2617	2696	2717	2698	2722	2690	2712	2681	2719	2632	2624	2698	2626	2698	2617
E500 5-1-8	1911	2516	2620	2669	2635	2669	2641	2644	2621	2677	2475	2514	2636	2461	2635	2461
E500 5-1-9	1967	2638	2715	2781	2712	2793	2760	2746	2689	2788	2554	2606	2758	2546	2712	2546
E500 5-1-10	1936	2555	2650	2673	2637	2683	2657	2644	2643	2677	2475	2547	2641	2496	2637	2475
E500 5-2-1	1382	2354	2573	2647	2564	2646	2601	2604	2533	2640	2344	2352	2521	2325	2564	2325
E500 5-2-2	1444	2470	2641	2681	2643	2678	2632	2650	2626	2674	2386	2410	2546	2378	2643	2378
E500 5-2-3	1433	2429	2667	2679	2655	2694	2673	2672	2668	2695	2394	2388	2593	2359	2655	2359
E500 5-2-4	1440	2431	2637	2688	2603	2679	2635	2631	2605	2683	2410	2462	2600	2357	2603	2357

Table D.4 Minimum makespans for 500-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 5-2-5	1490	2412	2593	2594	2593	2626	2585	2608	2562	2620	2451	2421	2528	2442	2593	2412
E500 5-2-6	1410	2487	2675	2754	2720	2758	2730	2716	2669	2755	2439	2492	2633	2438	2720	2438
E500 5-2-7	1356	2401	2568	2603	2561	2616	2580	2596	2548	2628	2317	2336	2521	2288	2561	2288
E500 5-2-8	1344	2374	2546	2632	2529	2649	2568	2609	2499	2633	2276	2320	2506	2264	2529	2264
E500 5-2-9	1457	2487	2605	2670	2629	2682	2625	2640	2588	2680	2458	2460	2595	2424	2629	2424
E500 5-2-10	1427	2369	2513	2594	2554	2599	2533	2553	2519	2600	2381	2382	2495	2324	2554	2324
E500 5-3-1	860	2280	2631	2715	2669	2690	2642	2686	2647	2707	2271	2283	2391	2226	2669	2226
E500 5-3-2	931	2240	2589	2637	2586	2656	2579	2643	2540	2671	2314	2288	2372	2247	2586	2240
E500 5-3-3	917	2272	2645	2706	2680	2737	2658	2701	2631	2721	2272	2293	2408	2236	2680	2236
E500 5-3-4	896	2298	2606	2653	2602	2653	2641	2619	2573	2648	2299	2311	2433	2260	2602	2260
E500 5-3-5	831	2111	2474	2594	2516	2567	2511	2569	2457	2574	2118	2152	2294	2068	2516	2068
E500 5-3-6	841	2193	2514	2591	2538	2612	2527	2584	2468	2588	2137	2147	2282	2112	2538	2112
E500 5-3-7	807	2138	2554	2614	2560	2618	2562	2579	2535	2613	2198	2204	2315	2143	2560	2138
E500 5-3-8	824	2213	2536	2600	2566	2605	2567	2557	2486	2607	2193	2196	2392	2157	2566	2157
E500 5-3-9	915	2273	2654	2691	2671	2712	2658	2686	2631	2708	2365	2348	2399	2315	2671	2273
E500 5-3-10	968	2244	2618	2649	2599	2631	2592	2628	2574	2647	2342	2370	2419	2261	2599	2244
E500 5-4-1	311	2015	2566	2671	2621	2658	2546	2678	2549	2658	2102	2067	2007	2055	2621	2007
E500 5-4-2	336	1965	2551	2649	2595	2683	2576	2643	2547	2679	2083	2012	2018	2050	2595	1965
E500 5-4-3	315	1964	2498	2593	2559	2617	2523	2605	2494	2609	2127	2070	2030	2100	2559	1964
E500 5-4-4	350	1995	2543	2681	2624	2687	2550	2646	2548	2685	2081	2073	2034	2073	2624	1995
E500 5-4-5	337	2046	2514	2625	2552	2636	2509	2637	2511	2655	2115	2111	2108	2099	2552	2046
E500 5-4-6	314	1932	2512	2617	2547	2632	2514	2609	2488	2595	2022	2052	1980	2056	2547	1932
E500 5-4-7	318	1817	2314	2459	2370	2506	2371	2448	2320	2448	1909	1910	1880	1941	2370	1817
E500 5-4-8	320	1895	2378	2474	2436	2509	2387	2462	2378	2486	1975	2003	1946	1941	2436	1895
E500 5-4-9	325	1850	2323	2509	2415	2525	2380	2486	2315	2515	1954	1935	1894	1943	2415	1850
E500 5-4-10	306	1922	2483	2563	2488	2589	2468	2571	2457	2609	2013	1996	1936	1988	2488	1922
E500 10-1-1	1862	2586	2698	2698	2661	2696	2695	2697	2659	2694	2572	2567	2652	2554	2694	2554
E500 10-1-2	1897	2698	2732	2738	2731	2737	2734	2734	2730	2738	2546	2597	2711	2547	2738	2546
E500 10-1-3	1968	2671	2772	2770	2760	2770	2770	2772	2765	2770	2658	2644	2748	2649	2770	2644

Table D.4 Minimum makespans for 500-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 10-1-4	2019	2791	2886	2889	2880	2889	2889	2886	2876	2889	2745	2760	2850	2752	2889	2745
E500 10-1-5	1975	2671	2748	2744	2706	2748	2748	2706	2706	2748	2685	2634	2715	2654	2748	2634
E500 10-1-6	1842	2589	2662	2665	2651	2665	2665	2662	2651	2665	2527	2538	2622	2512	2665	2512
E500 10-1-7	1943	2724	2828	2828	2820	2828	2828	2828	2820	2828	2702	2691	2806	2692	2828	2691
E500 10-1-8	2020	2676	2744	2746	2701	2746	2744	2744	2701	2744	2660	2670	2701	2665	2744	2660
E500 10-1-9	2146	2839	2907	2912	2907	2912	2909	2907	2907	2909	2855	2853	2884	2857	2909	2839
E500 10-1-10	1845	2618	2729	2734	2683	2734	2734	2731	2683	2734	2561	2605	2688	2566	2734	2561
E500 10-2-1	1382	2499	2684	2678	2659	2679	2671	2684	2654	2678	2435	2458	2587	2423	2678	2423
E500 10-2-2	1536	2598	2780	2781	2780	2781	2780	2781	2780	2781	2617	2611	2691	2568	2781	2568
E500 10-2-3	1467	2646	2837	2841	2802	2849	2838	2838	2804	2845	2593	2600	2741	2580	2845	2580
E500 10-2-4	1446	2611	2767	2773	2745	2773	2773	2761	2745	2773	2592	2568	2696	2564	2773	2564
E500 10-2-5	1392	2436	2678	2681	2663	2681	2676	2679	2673	2681	2375	2400	2584	2362	2681	2362
E500 10-2-6	1416	2548	2746	2771	2761	2771	2763	2765	2745	2767	2498	2492	2659	2477	2767	2477
E500 10-2-7	1510	2655	2869	2878	2843	2884	2865	2881	2881	2882	2634	2642	2755	2598	2882	2598
E500 10-2-8	1400	2550	2733	2736	2729	2736	2735	2732	2732	2736	2484	2500	2653	2470	2736	2470
E500 10-2-9	1363	2468	2623	2646	2616	2645	2639	2628	2605	2652	2429	2417	2556	2420	2652	2417
E500 10-2-10	1428	2591	2743	2743	2734	2743	2743	2743	2728	2743	2551	2538	2662	2506	2743	2506
E500 10-3-1	860	2355	2784	2808	2794	2809	2807	2808	2770	2808	2371	2318	2503	2357	2808	2318
E500 10-3-2	844	2252	2695	2714	2691	2720	2703	2714	2689	2715	2258	2286	2427	2221	2715	2221
E500 10-3-3	931	2452	2894	2903	2880	2893	2897	2907	2872	2899	2482	2402	2580	2414	2899	2402
E500 10-3-4	898	2326	2735	2744	2713	2737	2734	2744	2706	2744	2314	2310	2482	2307	2744	2307
E500 10-3-5	904	2391	2734	2756	2734	2748	2740	2745	2734	2748	2366	2318	2493	2300	2748	2300
E500 10-3-6	927	2315	2767	2771	2742	2764	2767	2762	2737	2769	2429	2344	2474	2360	2769	2315
E500 10-3-7	938	2253	2637	2650	2628	2649	2640	2651	2620	2642	2325	2319	2433	2296	2642	2253
E500 10-3-8	810	2280	2689	2711	2712	2712	2680	2721	2687	2722	2226	2217	2450	2227	2722	2217
E500 10-3-9	849	2204	2607	2608	2590	2607	2607	2608	2590	2608	2272	2230	2349	2204	2608	2204
E500 10-3-10	883	2313	2741	2745	2740	2746	2741	2741	2734	2752	2316	2319	2474	2319	2752	2313
E500 10-4-1	311	1999	2788	2807	2805	2806	2787	2809	2784	2826	2129	2056	2027	2089	2826	1999
E500 10-4-2	299	1921	2623	2652	2621	2651	2622	2651	2617	2644	2037	1965	2005	2040	2644	1921

Table D.4 Minimum makespans for 500-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 10-4-3	308	1999	2729	2782	2754	2778	2713	2759	2731	2776	2090	2027	2071	2081	2776	1999
E500 10-4-4	313	1914	2658	2669	2673	2687	2657	2665	2650	2673	2033	1988	1976	2035	2673	1914
E500 10-4-5	315	1984	2714	2727	2711	2736	2710	2738	2706	2743	2101	2028	2030	2088	2743	1984
E500 10-4-6	313	1953	2701	2706	2702	2707	2701	2707	2700	2710	2071	2030	1981	2075	2710	1953
E500 10-4-7	307	1966	2705	2723	2699	2719	2704	2716	2699	2724	2074	2017	2054	2075	2724	1966
E500 10-4-8	326	1919	2687	2695	2689	2702	2698	2699	2685	2701	2037	1992	1996	1992	2701	1919
E500 10-4-9	320	1993	2774	2781	2765	2788	2771	2773	2752	2773	2133	2041	2064	2092	2773	1993
E500 10-4-10	316	1958	2681	2694	2690	2693	2693	2700	2689	2696	2171	2011	1997	2069	2696	1958
E500 15-1-1	1862	2628	2702	2702	2634	2702	2702	2702	2634	2702	2599	2585	2668	2574	2702	2574
E500 15-1-2	2020	2718	2769	2769	2711	2769	2769	2714	2711	2769	2685	2689	2738	2672	2769	2672
E500 15-1-3	1994	2718	2779	2779	2721	2779	2779	2774	2745	2779	2698	2685	2741	2689	2779	2685
E500 15-1-4	1980	2670	2747	2747	2746	2747	2747	2747	2746	2747	2678	2665	2715	2691	2747	2665
E500 15-1-5	1977	2676	2762	2762	2756	2762	2762	2762	2756	2762	2660	2635	2737	2650	2762	2635
E500 15-1-6	2075	2756	2836	2836	2766	2836	2836	2836	2766	2836	2758	2743	2796	2759	2836	2743
E500 15-1-7	1933	2627	2692	2692	2652	2692	2692	2652	2652	2692	2611	2615	2679	2604	2692	2604
E500 15-1-8	1836	2616	2708	2708	2662	2708	2708	2708	2697	2708	2542	2566	2668	2537	2708	2537
E500 15-1-9	1994	2703	2756	2756	2691	2756	2756	2756	2691	2756	2692	2684	2730	2686	2756	2684
E500 15-1-10	1885	2544	2602	2602	2601	2602	2602	2602	2601	2602	2495	2499	2577	2474	2602	2474
E500 15-2-1	1382	2510	2686	2686	2663	2686	2686	2686	2663	2686	2476	2481	2589	2460	2686	2460
E500 15-2-2	1408	2553	2701	2701	2677	2701	2701	2701	2679	2701	2518	2489	2636	2487	2701	2487
E500 15-2-3	1363	2524	2702	2702	2696	2702	2702	2702	2696	2702	2498	2459	2616	2494	2702	2459
E500 15-2-4	1465	2552	2718	2718	2695	2718	2718	2718	2695	2718	2551	2530	2624	2543	2718	2530
E500 15-2-5	1862	2628	2702	2702	2634	2702	2702	2702	2634	2702	2599	2585	2668	2574	2702	2574
E500 15-2-6	2020	2718	2769	2769	2711	2769	2769	2714	2711	2769	2685	2689	2738	2672	2769	2672
E500 15-2-7	1994	2718	2779	2779	2721	2779	2779	2774	2745	2779	2698	2685	2741	2689	2779	2685
E500 15-2-8	1980	2670	2747	2747	2746	2747	2747	2747	2746	2747	2678	2665	2715	2691	2747	2665
E500 15-2-9	1977	2676	2762	2762	2756	2762	2762	2762	2756	2762	2660	2635	2737	2650	2762	2635
E500 15-2-10	2075	2756	2836	2836	2766	2836	2836	2836	2766	2836	2758	2743	2796	2759	2836	2743
E500 15-3-1	1933	2627	2692	2692	2652	2692	2692	2652	2652	2692	2611	2615	2679	2604	2692	2604

Table D.4 Minimum makespans for 500-activity instances (cont'd)

Project Name	Minimum Makespan Value															
	ES	MSP 2019	PRIMAVERA 2019								ASTA 2019				SSS	Min.
		Standard	ID (Asc.)	ID (Desc.)	TF (Asc.)	TF (Desc.)	ES (Asc.)	ES (Desc.)	LF (Asc.)	LF (Desc.)	TF	ID	TS	MP	ID	
E500 15-3-2	1836	2616	2708	2708	2662	2708	2708	2708	2697	2708	2542	2566	2668	2537	2708	2537
E500 15-3-3	1994	2703	2756	2756	2691	2756	2756	2756	2691	2756	2692	2684	2730	2686	2756	2684
E500 15-3-4	1885	2544	2602	2602	2601	2602	2602	2602	2601	2602	2495	2499	2577	2474	2602	2474
E500 15-3-5	1382	2510	2686	2686	2663	2686	2686	2686	2663	2686	2476	2481	2589	2460	2686	2460
E500 15-3-6	1408	2553	2701	2701	2677	2701	2701	2701	2679	2701	2518	2489	2636	2487	2701	2487
E500 15-3-7	1363	2524	2702	2702	2696	2702	2702	2702	2696	2702	2498	2459	2616	2494	2702	2459
E500 15-3-8	1465	2552	2718	2718	2695	2718	2718	2718	2695	2718	2551	2530	2624	2543	2718	2530
E500 15-3-9	1363	2557	2759	2761	2750	2761	2759	2761	2750	2761	2531	2517	2670	2500	2761	2500
E500 15-3-10	1475	2692	2841	2845	2807	2845	2841	2841	2803	2841	2625	2600	2760	2633	2841	2600
E500 15-4-1	1420	2474	2634	2634	2634	2634	2634	2634	2634	2634	2481	2492	2545	2464	2634	2464
E500 15-4-2	1443	2634	2788	2788	2785	2788	2788	2788	2785	2788	2549	2556	2705	2519	2788	2519
E500 15-4-3	1438	2560	2724	2724	2697	2724	2724	2724	2697	2724	2572	2535	2659	2559	2724	2535
E500 15-4-4	1517	2701	2865	2865	2843	2865	2865	2854	2846	2865	2690	2676	2782	2669	2865	2669
E500 15-4-5	860	2417	2809	2809	2797	2809	2809	2809	2797	2809	2450	2386	2607	2383	2809	2383
E500 15-4-6	836	2397	2847	2847	2830	2844	2844	2847	2830	2847	2434	2349	2550	2383	2847	2349
E500 15-4-7	883	2346	2662	2662	2652	2662	2662	2662	2652	2662	2373	2325	2464	2345	2662	2325
E500 15-4-8	301	2091	2461	2461	2461	2461	2461	2461	2461	2461	2130	2114	2126	2125	2461	2091
E500 15-4-9	322	2024	2785	2792	2792	2792	2785	2792	2792	2792	2133	2051	2087	2124	2792	2024
E500 15-4-10	301	1889	2629	2636	2627	2637	2628	2637	2621	2636	1997	1916	1936	1966	2636	1889