

THE RESOURCE ALLOCATION CAPABILITIES OF COMMERCIAL  
PROJECT MANAGEMENT SOFTWARE PACKAGES FOR RESOURCE  
CONSTRAINED PROJECT SCHEDULING PROBLEM

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# **ABSTRACT**

## **THE RESOURCE ALLOCATION CAPABILITIES OF COMMERCIAL PROJECT MANAGEMENT SOFTWARE PACKAGES FOR RESOURCE CONSTRAINED PROJECT SCHEDULING PROBLEM**

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Resource constrained project scheduling problem (RCPSP) has been subject of extensive research in project management literature as RCPSP is one of the most challenging problems in the project management and is of great practical importance. In this thesis, resource allocation capabilities of Primavera Enterprise V.6.0-Project Management (P6) and MS Project 2007 (MS) were evaluated for solving overallocated problems in the RCPSP. Forty-five resource overallocated instance projects were selected from the PSPLIB to evaluate performance of P6 and MS Project 2007. Three resource allocation priority rules of P6 and two resource allocation priority rules of MS were used for comparison. The best solutions of different priority rules for P6 and MS were compared by using t-test. Results of the P6 and MS were compared with the lower bounds and optimum solutions of the previous heuristic methods. The comparisons indicate that both P6 and MS has limited capabilities for solving overallocated problems in RCPSP. Especially for larger projects the widely used project management software packages can not provide optimum or near optimum solutions.

Key Words: Project Scheduling, Project Management Software Packages, Resource Allocation

# ÖZ

## KISITLI KAYNAK KULLANIMLI PROJE ÇİZELGELEMESİ PROBLEMLERİNDE TİCARİ PROJE YÖNETİMİ YAZILIMLARININ KAYNAK DAĞITIM KABİLİYETLERİ

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Kısıtlı kaynak kullanımlı proje çizelgelemesi problemleri (KKKPCP) hem zor bir problem olduğundan hem de pratik uygulamalar açısından önem taşıdığından proje yönetimi literatüründe önemli bir araştırma konusu olmuştur. Bu tezde, Primavera Enterprise V.6.0 - Project Management (P6) ve MS Project 2007 (MS)'nin KKKPCP'nde, aşırı kaynak yüklenmiş problem çözümleri için kaynak dağıtım kabiliyetleri değerlendirilmiştir. P6 ve MS Project 2007'nin performansını değerlendirmek için PSPLIB'den 45 adet aşırı kaynak yüklenmiş örnek proje seçilmiştir. P6'nın üç kaynak atama önceliği ve MS'nin iki kaynak atama önceliği kıyaslanmıştır. Farklı kaynak atama önceliklerine göre P6 ve MS'nin en iyi çözümleri t-test kullanılarak kıyaslanmıştır. P6 ve MS'nin sonuçları alt sınır değerleriyle ve önceki çalışmalarda sezgisel yöntemler kullanılarak elde edilmiş optimum sonuçlarla kıyaslanmıştır. Kıyaslamalar P6 ve MS'nin KKKPCP'nde, aşırı kaynak yüklenmiş problem çözümleri için sınırlı kapasiteleri olduğunu göstermiştir. Yaygın olarak kullanılan proje yönetimi programları özellikle çok aktiviteli projeler için optimum ya da optimuma yakın değerleri sağlayamamıştır.

Anahtar Kelimeler: Proje Çizelgelemesi, Proje Yönetimi Yazılım Paketleri, Kaynak Dağılımı

To My Family

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## LIST OF ABBREVIATIONS

CPM	: Critical Path Method
EPWM	: Enhanced Positional Weighted Method
FBI	: Forward Backward Improvement
LFT	: Late Finish Time
LR	: Lagrange Relaxation
LST	: Late Start Time
MS	: Microsoft Office Project 2007
MSLK	: Minimum Slack
P6	: Primavera Enterprise V.6.0-Project Management
PERT	: Program Evaluation and Review Technique
PMBOK	: Project Management Body of Knowledge
PMI	: Project Management Institute
RCPSP	: Resource Constrained Project Scheduling Problem
RPWM	: Ranked Positional Weighted Method
SGS	: Schedule Generation Scheme
TF	: Total Float

# CHAPTER 1

## INTRODUCTION

Project Management Institute (PMI) defines (Project Management Institute, 2004) project as a ‘temporary endeavor undertaken to create a unique product or service’ in Project Management Body of Knowledge (PMBOK). Temporary endeavour (having definite start and completion dates) resulting in a permanent unique product requires skillful project management. Every project is unique with different scope even for the same kind of building project including different technology, space and sequencing. Then, project constraints which are budget and schedule are unique desiring elaborate project management. The primary challenge of project management is to achieve project objective namely project scope within the project constraints (budget and schedule) satisfying quality and safety requirements. . The secondary—and more ambitious—challenge is to optimize the allocation and integration of resources like money, people, materials, machinery, energy, space, provisions, etc. necessary to meet pre-defined objectives by the owner/client.

Broadly these objectives, which are called project triangle, must meet three fundamental criteria:

1. The project must be completed on time, within the planned schedule;
2. The project must be accomplished within the planned budgeted cost;
3. The project must meet the prescribed quality and safety requirements.

**Critical Path Method (CPM)** is also known as **critical path analysis**, is a mathematically based algorithm for scheduling a set of project tasks. It is a significant tool for effective project management.

Originally, the critical path method considered only logical dependencies between activities. CPM usage expanded to allow for the inclusion of resources related to each activity, through processes called activity-based resource assignments and then resource leveling emphasized its importance. **Resource Leveling** is a project management process used to examine a project for an unbalanced use of resources (usually people or machinery) over time, and for resolving over-allocations or conflicts.

The Project conditions will require scheduling certain tasks simultaneously when more resources such as machines or people are assigned than are available, or perhaps a specific person such as skilled labor, engineer or manager is needed in both tasks, the tasks will have to be rescheduled concurrently or even sequentially to manage the constraint which is called resource overallocation problem. Resource leveling can be used to balance the workload of primary resources over the course of the project.

When using specially designed project software packages, leveling resources typically means resolving conflicts or over allocations in the project plan by allowing the software to calculate delays due to resource overallocation. Project management software leveling may delay activities due to resource constraints. A resource-leveled schedule may include delays due to resource overallocation (i.e., unavailability of a resource at the required time), and may cause a longer critical path than the previously critical path to become the longest or "resource critical" path.

Conventional scheduling techniques like CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique) just study the time aspect. The goal of these methods is minimizing the project duration, assuming that all resources required by the project are enough for activity assignments or unconstrained resource case meaning no resource constraint. However, in practice, the situation is different, project completion requires the use of various resources like labor, nonlabor, and materials. The limited availability of the project resources

unfavorably affects owner expectations like finishing project on time within budget meeting quality and safety requirements.

Both of CPM and PERT make use of the network idea in planning and scheduling projects. They are both time-oriented methods in the sense that they both deal with the determination of a time schedule for the project. The difference is that the durations of activities are assumed to be deterministic in CPM, whereas they are described to be probabilistic in PERT.

Differently from conventional scheduling methods real life project scheduling is concerned with the allocation of the resources and finishing of the activities subject to the precedence and resource constraints. The resource leveling and resource allocation are two different problems in resource management. Resource Leveling appears, when enough resources are available and one tries to keep the resource usage as much as possible at a fixed rate. The resource allocation problem forms when total resource usage is restricted to a given limit and the aim is to allocate overallocated resources to the activities in such a way that the makespan is minimized.

The project management process will have the same major stages:

- initiation,
- planning,
- execution,
- reporting and controlling,
- closing.

In this study, we concentrate on planning stage. Most of the project stakeholders confuse about two definition, planning and scheduling phase. Planning also includes scheduling phase. There is a slight difference between the scheduling stage and the planning stage. These phases can be summarized as follows:

**The scheduling stage:** CPM is generally used in this stage. To obtain critical path Forward-Pass and Backward-Pass rules are applied for activities. Forward pass

produce the earliest start and finish times and the backward pass provide latest allowable ones for each activity. The difference between late and early times gives total floats of activities, and identify the critical activities with zero float values through the network.

**The planning stage:** Resources are determined for corresponding activities. Maximum availability and estimate usage of resources are assigned to the activities according to bill of quantities and past records (esp. productivity data for man-hour and equipment-hour) related to materials. Resource leveling is applied in this stage. Forward-level and backward-level rules are applied for the schedule. Leveling resources in projects ensures that resource demand does not exceed resource availability. Resource leveling is a process that may change the start of certain activities. During leveling, the resource requirements of all scheduled activities are compared to the maximum quantity available at the time of leveling. An activity is delayed if resources are not available at any time during the activity's duration. It is possible to select the resources to be leveled, and we can add leveling priorities that specify which project or activity is leveled first when a conflict occurs. In the planning phase, the time-cost trade-off of activity performance times may be considered if the analyst is interested in determining the cost of reducing the project completion time or comparing the indirect costs plus penalty costs with the cost of reducing the project completion.

In this study, the basic planning phase with resource allocation is considered for the case of limited renewable resources which is called resource constrained project scheduling problems (RCPS) with the selection of overallocated resource problems.

The overallocated resource problem occurs when activity based resource assignments are available in constrained amounts and the resource assignments of parallel activities exceed the availability. In practical project management applications, management stakeholders of the project have to cope with not only the preceding activity constraints but more challenging one, limited resources, such as fixed manpower, machinery and material availabilities. Resource constraints of the

activities may result in an increase in project completion time. Classical makespan minimization is the reducing the project completion time for RCPSP by evaluating resource limitations and deciding resource assignments for the activities.

Liberatore et al. (2001) carried out a survey about project management software usage in construction industry. Liberatore et al. (2001) identified that Primavera is the most frequently used software package, while Microsoft Project is used by less than a quarter of the total in the construction industry. The results they found from the survey results was as follows; MS Project usage was 24.3 % and Primavera usage was 51.4 % among the project management software usage in the construction industry. Since total usage of Primavera and MS Project is more than % 75, it would be right choice making necessary analysis with the two widely used commercial project management software packages.

In this study, Primavera Enterprise V.6.0-Project Management (P6) and Microsoft Office Project 2007 (MS) were used to compare the resource allocation capabilities of commercial project management software packages for overallocated resource problems. The reason for selecting these packages is that these two are the most popular packages in international construction projects as stated above. P6 has ability to convert Primavera Enterprise V.6.0-Project Management (P6) data to Microsoft Office Project 2007 (MS) data. P6 and MS give the user an option when scheduling with resource leveling to determine leveling priority rule for resolving the overallocation of resources.

The rest of the thesis is organized as follows: The problem definition for RCPSP is presented and literature review is explained on single-mode RCPSP in Chapter 2.

Performance of P6 & MS Project 2007 are compared in terms of resource allocation capabilities for overallocated resource problems in Chapter 3. Conclusion is given in Chapter 4.

## CHAPTER 2

### PROBLEM DEFINITION AND LITERATURE REVIEW

#### 2.1 RCPSP Definition

Numerous research have focused on minimization of makespan for the resource–constrained project scheduling problem (RCPSP). Project management stakeholders are highly interested in reducing the project completion duration due to the contract conditions. Most of the projects are time bounded, it means there is a significant amount of tardiness cost. In addition, long project duration means additional indirect cost. In some projects it may be vital to reduce project completion time by allocation of the scarce resources. RCPSP concentrates on resource allocation in constrained resource environment to minimize makespan of project completion.

Kolisch and Hartmann (2006) defined the resource–constrained project scheduling problem (RCPSP) as follows: A single project consists of a number of  $n$  activities where each activity has to be processed in order to complete the project. The activities are interrelated by two kinds of constraints. First, precedence constraints force activity  $j$  not to be started before all its immediate predecessors have been finished. Second, performing the activities requires resources with limited capacities. Altogether there is a set of  $R$  resources. While being processed, activity  $j$  requires  $r_{j,k}$  units of resource  $k \in R$  in every time instant of its non–preemptable duration  $p_j$ . Resource  $k$  has a limited capacity of  $R_k$  at any point in time. The parameters  $p_j$ ,  $r_{j,k}$ , and  $R_k$  are assumed to be nonnegative and deterministic. The objective of the RCPSP is to find precedence and resource feasible completion times for all activities such that the makespan of the project is minimized.

According to categories activity based resources are classified by Blazewicz et al. (1983). There are four categories for resources that are renewable, nonrenewable, doubly constrained and partially renewable. Kolisch and Padman (2001) defined these four type resources as follows;

**Renewable resources** are limited on a per period basis only. They are available for every single period. Machines (nonlabor), equipment (material), and manpower (labor) are the examples for renewable resources.

**Nonrenewable resources** are limited over the project length, with no restrictions within each period, limited for the entire project. Capital budget of a project is the example for nonrenewable resources.

**Doubly constrained resources** are limited on a period basis as well as on total project duration. Budget constraints that limit capital availability for the entire project as well as limiting its consumption over each time period is an example of this type of resource.

**Partially renewable resources**, are limited utilization of resources within a period of the project length. An example is workers whose weekly working time, not the daily time, is limited by the working contract in a project with length of a month.

Finally, each resource type has a value associated with it, representing the available amount. Whenever there is at least one category of constrained resources, the resulting PSP is called as a resource-constrained project scheduling problem (RCPP) (Kolisch and Padman 2001).

Scheduling and logical sequencing are complementary and are both dealt with the optimal allocation of limited resources over time. Defining the activities and its corresponding durations is called scheduling. Logical sequencing concerns the ordering in which the activities have to be performed as parallel or serial considering the number of crews. Resource-constrained project scheduling problem is the scheduling of a project in order to minimize its duration, with zero-lag finish to start precedence constraints between the activities and constant availability constraints on the activity based assignments of renewable resources. Significant

progress has been made using optimal solution procedures for RCPSP over the past few years.

## **2.2 Literature Review**

The resource-constrained project scheduling problem (RCPSP) is known to be NP-Hard (Blazewicz et al., 1983), which implies that the resolution of large instances with an exact method is very time consuming. Several solution procedures have been proposed in the literature.

Surveys on several solution procedures can be found in Kolisch and Hartmann (2006), Demeulemeester and Herroelen (2002), Kolisch and Padman (2001), Hartmann and Kolisch (2000), Kolisch and Hartmann (1999), Brucker and Knust (1999), and Herroelen et al. (1998).

RCPSP studies in the literature are presented into four groups as;

- exact algorithms,
- heuristic and metaheuristic procedures,
- data sets and problem generation
- previous research that evaluates performance of commercial project management software packages for RCPSP.

### **2.2.1 Exact Algorithms**

Implicit enumeration with branch and bound is the best method so far for the exact solution of the RCPSP to obtain optimum results.

The fundamental conclusions which can be drawn from the reviewed research by Herroelen et al. (1998) on branch-and-bound schemes for the RCPSP can be summarized as follows:

The most effective dominance pruning rule is the cutset dominance rule, especially with a sufficient amount of memory. DH-procedure (Demeulemeester and

Herroelen 1992) and its extensions DH1 (Demeulemeester and Herroelen 1997) and DH2 (Herroelen et al. 1998) use an effective cutset dominance rule.

Depth-first branch-and-bound procedures offer the best potential for solving the RCPSP as the state of the art. Demeulemeester and Herroelen (1992) developed depth-first DH-procedure which utilizes the most efficient solution logic. Demeulemeester and Herroelen (1997) developed the more efficient DH1-procedure by implementing of a new version of a dominance rule into DH-procedure with the use of 32-bit programming which runs on a Windows NT 3.50 platform. DH1-procedure resulted in 10 times speedier than the DH-procedure, as compared to the code used for the Demeulemeester and Herroelen (1992) paper, on the 110 Patterson problems. Improving the code further reduced the computational effort to a negligible level in DH2-procedure.

Truncated depth-first branch-and-bound procedures give near-optimal solutions providing an appropriate alternative to priority based heuristics. The significance of truncated branch-and-bound procedures realized by computational experience gained on a wide variety of test instances. Herroelen et al. 1998 stated that the quality of the optimal solutions obtained by truncated branch-and-bound procedures outperforms the solution quality of many heuristics in terms of computational time. Truncated exact procedures are also good for solving real problems, sufficiently large size, within an acceptable computational burden and with acceptable solution quality (Herroelen et al. 1998).

Kolisch et al. (1995) developed a problem generator that is called ProGen. ProGen has been used to generate a set of RCPSP test instances which currently serves as the benchmark test set. The DH2 procedure has optimally solved 480 RCPSP test instances for 30 activities in an average CPU-time of 0.37 s (with a maximum of 50.97 s) on a 200 MHz Pentium Pro personal computer. The significant point is that making the trade-off between the strength of the bounds or dominance rules used and the time required for their computation; The DH1-procedure optimally solves the 480 instances for 30 activities requiring that one of the problems needed 3 h of

computation time. Moreover, a truncated version of the procedure yields excellent results. Running the DH1-procedure for small amounts of time yields solutions which are very close to the optimum. The DH2-procedure leads to a further gain in efficiency. These results constitute for 480 RCPSP test instances for 30 activities as a new benchmark for the RCPSP.

### **2.2.2 Heuristic and Metaheuristic Procedures**

In a recent study Kolisch and Hartmann (2006) conducted a survey on the heuristic methods for resource-constrained project scheduling problem. They employed the three test sets J30, J60, and J120 that have been constructed by the instance generator ProGen (Kolisch et al. 1995). The projects consisted of 30, 60, and 120 activities, respectively. In total, they used 480 instances with 30 activities, 480 instances with 60 activities, and 600 instances with 120 activities. They hold particular methods which use the serial or parallel schedule generation scheme (SGS); one pass of an SGS with one start time assignment per activity counts as one schedule. As their previous comparison of 1000 and 5000 schedule they have also used 50,000 schedules as an additional limit (Kolisch and Hartmann 2000). The genetic algorithm of Hartmann (1998) and the simulated annealing procedure of Bouleimen and Lecocq (2003) were previously found out as the best performing approaches by Kolisch and Hartmann (2000). Again, they found out that the best performing methods are metaheuristics (Kolisch and Hartmann 2006). However, for the RCPSP, pure genetic algorithms are not sufficient anymore. The basic genetic algorithm scheme is adjusted by integrating further features such as path relinking, forward-backward improvement (FBI), selfadapting mechanisms, non-standard crossover techniques give better results. Modifications and extensions are applied within the same heuristic lead to excellent results. However, all modifications and extensions do not actually contribute to the performance.

Kolisch (1996) explained that there are two different schemes which are the serial and the parallel method for the generation of feasible schedules. A specific priority

rule is then employed in order to choose one activity from the decision set which will be scheduled.

Valls et al. (2004) demonstrated that FBI can easily be added to any existing heuristic for the RCPSP since it can be applied to any intermediate schedule. This makes FBI a promising building block of heuristics. Common feature of the best solution methods are forward–backward improvement. They expect that forward–backward improvement will become an important component in future heuristics for the RCPSP. Valls et al. (2005) utilized FBI in addition to random sampling resulting in much better results than adding a priority rule which is made up of two components, a schedule generation scheme and a priority rule.

Last experimental investigation conducted by Kolisch and Hartmann (2006) showed that: Alcaraz et al. (2004), Debels et al. (2006), Hartmann (2002), Kochetov and Stolyar (2003), and Valls et al. (2003 and 2005) outperformed the former benchmarks. These heuristics include FBI were among the best in their study, as dominating heuristics. Valls et al. (2005) also showed the power of FBI who add it to the simplest project scheduling heuristic, i.e. pure random sampling.

Metaheuristics, such as genetic algorithms and tabu search, has been the most popular strategies. Although a few researchers have extended the activity list’s classical form it has been the most widely used representation. The methods used by Baar et al. (1998), Bouleimen and Lecocq (1998), Hartmann (1998), and Pinson et al. (1994) employ a so-called ‘activity list’, where a schedule is generated by scheduling the activities in the order prescribed by the list, were different with respect to the proposed neighborhoods and metaheuristic strategies (Kolisch and Padman 2001).

Priority rule-based X-pass methods have attracted less attention as Kolisch and Hartmann (2000 and 2006) asserted that priority rule-based X-pass methods are inferior to metaheuristic approaches which are capable of learning. Several methods like Lagrange method and strategies based on decomposition and optimization have been developed which can neither be classified as X-pass methods nor as metaheu-

ristics. In fact these approaches do not give encouraging results. Kolisch and Hartmann (2006) recommended that both scheduling directions instead of only forward scheduling, both SGS instead of only one, since neither the serial nor the parallel SGS is consistently superior it appears to be a good idea to employ both. As a result using the parallel SGS in addition to the serial one improves the results, more than one type of local search operator, or even more than one type of metaheuristic strategy.

### **2.2.3 Data Sets and Problem Generation**

#### **Data Sets**

In order to evaluate the solution procedures as benchmark the need for data sets arose for RCPSP on literature. Although a solution procedure gives very good performance on an instance, it might not show good enough results on another. General idea about the algorithms only can be drawn from benchmarks. To standardize these data sets, bank of data sets were created.

As Kolisch and Padman (2001) discussed in data sets, Davis (1969) generated 83 instances of the RCPSP as the first to generate project scheduling instances for benchmarking and testing. Later Patterson (1974) was the second by generating 11 instances and Talbot and Patterson (1978) was the third by generating 10 more. Patterson (1984) achieved total of 110 instances and gathered the optimal solutions for this problems to obtain the minimum makespan objective using all the known algorithms. These 110 instances, known as the Patterson problems, were later used in several studies. The great benefit of the Patterson problems was the availability of optimal makespan values and the wide usage of the test set for both optimal and heuristic algorithm evaluation. Patterson problems had a major disadvantage that the instances were not generated based on well-defined problem parameters. Herroelen et al. (1998) stated that all Patterson problems, which for many years has served as the de facto standard test set, can be solved optimally by the DH2 procedure in an average CPU-time of 0.002 s on a Pentium Pro processor with 200

MHz clock pulse. Herroelen et al. (1998) asserted that Patterson problems can no longer uniquely serve as the benchmark test set for the RCPSP. Alvarez-Valdes and Tamarit (1989) generated a new test set, 144 instances, utilizing a full factorial design with five different problem parameters. Kolisch et al. (1992 and 1995) proposed an instance generator for a general class of project scheduling problems and also determined a new problem parameter, called resource strength, which can be applied to different categories and types of resources. By using the resource strength and other parameters within a full factorial experimental design, Kolisch et al. (1995) generated test sets for the single- and the multi-mode RCPSP, the former with 480 and the latter with 640 instances, and 536 of them with feasible solutions. Kolisch and Sprecher (1996) have added additional benchmark problems to the two sets mentioned above.

The single- and the multi-mode RCPSP are set in the project scheduling problem library (PSPLIB) and can be downloaded from the site [129.187.106.231/psplib](http://129.187.106.231/psplib) to be used as a benchmark.

### **Problem Generation**

As Kolisch and Padman (2001) discussed in problem generation part, there have been many problem generators employed for the experimental testing of procedures. Only a few have been made available to the public. Demeulemeester et al. (1993) were the first who focused on generating strongly random AOA networks for a given number of arcs and nodes. Kolisch et al. (1992 and 1995) were the first to program a general-purpose project generator, called ProGen, for a broad class of different problems in the AON representation. They include different objective functions, single- and multi-mode activities, different categories of resources and single and multi-project scheduling problems. The program is capable of generating projects subject to well-defined problem parameters.

#### **2.2.4 Previous Research that Evaluates Performance of Commercial Project Management Software Packages for RCPSP**

Kastor and Sirakoulis (2008) analyzed the quality of project management software for resource constrained scheduling, by evaluating Primavera P6.0 and Microsoft Project 2007, and Open Workbench 1.1.6 on two real construction projects to show that the duration of the project, when considering resource constraints, depends on the software and/or the method used. One of the instance they used as benchmark was a real housing project which consisted of 98 activities and 1 renewable resource. The second instance they used as benchmark was the construction of a shopping mall consisting of 668 activities and 7 renewable resources. They used a standard built-in procedure for Microsoft Project and Open workbench since there is one result for each. They used six priority rules and all possible combinations between them for P6 besides the default resource levelling obtained 31 results. The priority rules for P6 used by them were Late Start Time (LST), Late Finish Time (LFT), Minimum Slack (MSLK), Ranked Positional Weighted Method (RPWM) and Enhanced Positional Weighted Method (EPWM). RPWM and EPWM do not exist in Primavera, but they computed and imported to Primavera as Custom Data Items. The comparison of these results made using the percentage deviation from the project duration without resource constraints namely CPM, which is 464 days for instance 1 and 238 for instance 2. They found out that;

- 1) Primavera P6 gave the best results and is followed by MS Project in both the instances.
- 2) Primavera P6 default and by LST rule gave the best solution for both instances with an average deviation of 41.11%.
- 3) MS Project is ranked 3 (46.14%) and is followed by P6 by RPWM and by LFT (47.19%).
- 4) The worst result was given by Open Workbench with an average deviation of 167.79%.

Hekimoğlu (2007) tested MS Project 2003 (MS) and Primavera Enterprise V.4.1-Project Management (PV) with its two priority rules minimum total slack (MINSLK) and latest finish time (LFT) for solving 2040 instances generated from ProGen under different parameter settings. The responses are found as the percentage mean deviation from the benchmark makespan. The results of their benchmark test problems show that only one out of 6120 instances was solved better than the state-of-the-art algorithms by using project management software packages. This better solution they found was obtained from PV-LFT. The mean and the standard deviations of the deviations for all instances indicated that PV-LFT gave the best results for every factor combinations except for the instances that have 30 activities. In those instances MS outperformed PV results. PV-MINSLK ranked last for all treatments. From their results they asserted that only for small problems MS should be preferred to PV-LFT, for the larger size problems PV-LFT should be used in order to obtain better results for RCPSP's. They told that PV-MINSLK method is not the proper choice for RCPSP's and PV-MINSLK ranked last for all treatments.

Mellentien and Trautmann (2001) presented an experimental performance analysis with Acos Plus.1 8.2 (Acos), CA SuperProject 5.0a (Computer Associates), CS Project Professional 3.0 (CREST Software), MS Project 2000 (Microsoft), and Project Scheduler 8.0.1 (Scitor). They used PSPLIB single-mode resource constrained problem instances consists of 480 projects with 30 activities, 480 projects with 60 activities, and 600 projects with 120 activities, and four renewable resources each which were generated by ProGen. They found out that Acos Plus has shown the best results for instances with 30, 60 and 120 activities with a mean percent deviation from makespan of the best known solutions with 3.87, 4.05 and 9.69 respectively. They found out that MS Project 2000 has shown the worst results for instances with 30, 60 and 120 activities with a mean percent deviation from makespan of the best known solutions with 5.18, 6.23 and 14.02 respectively.

In previous study earlier versions of commercial project management software were used to solve RCPSP. In the latest study MS Project 2003 (MS) and Primavera

Enterprise V.4.1-Project Management (PV) were used for RCPSP from PSPLIB by Hekimoğlu (2007). The main objective of this study is to evaluate the capabilities of latest versions commonly used project management software, MS Project 2007 and Primavera Enterprise V.6.0-Project Management for solving RCPSP.

## **CHAPTER 3**

### **PERFORMANCE OF P6 & MS PROJECT 2007 FOR RCPSP**

In this chapter the resource allocation capabilities of P6 and MS Project 2007 are tested for RCPSP. 45 randomly selected overallocated resource constrained projects for different activities are used. The test sample included 15 resource overallocated projects with 30 activities, 15 resource overallocated projects with 60 activities and 15 projects with 120 activities which were generated by ProGen. First selection procedure of resource leveling priorities are presented and performance measures are stated. Then the determined resource leveling priorities are used to evaluate the resource allocation capabilities of P6 and MS Project 2007. Best results of P6 and MS Project 2007 are discussed with optimum, lower bound and heuristic solutions for RCPSP. Finally, t-paired test is used to analyze the results.

#### **3.1 Selection of Significant Resource Leveling Priorities**

Since commercial project management software packages are proprietary, they usually do not explain the algorithms they used for resource allocation. 10 iterations were made consecutively for each resource leveling priorities by trial and error. The combination of different resource leveling priorities are also tested.

Resource Leveling Priorities that are conducted as shown below;

1. P6 Default with 10 iterations consecutively
2. P6 Total Float (TF) with 10 iterations consecutively
3. P6 Late Finish Time (LFT) with 10 iterations consecutively
4. Combination of P6 Default and P6 LFT with 10 iterations consecutively

5. Combination of P6 Default and P6 TF with 10 iterations consecutively
6. Combination of P6 LFT and P6 TF with 10 iterations consecutively
7. MS Project 2007 with Standart
8. MS Project 2007 with ID
9. MS Project 2007 with Priority/Standart

9 leveling methods mentioned above are used for randomly selected 9 projects with 30 activities (J=30) which are generated by ProGen. For 9 leveling methods with 9 randomly selected projects with 10 iterations, totally P6-> (9 projects \* 6 methods \* 10 iterations) + MS Project 2007-> (9 projects \* 3 methods) = 567 iterations for deciding the significant resource leveling method with P6 and MS Project 2007. Random function is used in excel for the selection of our samples which are generated by ProGen from PSPLIB.

The results of the nine leveling priority rules for the nine randomly selected projects with 30 activities are given in Tables A-1 to A-7 in appendix part. After analyzing 567 iteration results for randomly selected 9 projects, it was concluded that some of these methods will be adequate for our analysis. The significant resource leveling priorities that will be used for the entire sample, 45 projects which are generated by ProGen from PSPLIB are determined as shown below;

1. P6 Default with 1 iteration
2. P6 Total Float with 10 iterations consecutively
3. P6 Late Finish with 2 iterations consecutively
4. MS Project 2007 with ID
5. MS Project 2007 with Standart

Selected leveling priority definitions can be summarized as follows;

1. P6 Default leveling gives priority to activities according to activity id in ascending order.

2. P6 TF leveling gives priority to activities with less total float or more critical activities first.
3. P6 LFT leveling gives priority to activities with earlier, late finish dates first.
4. MS Project 2007 ID leveling gives priority to activities according to activity id in ascending order.
5. MS Project 2007 Standart leveling priority is not konown since it is proprietary.

First comparision was between MS and P6 results to reveal which one is better as the widely used commercial project management software package in construction industry. Specific attention should be paid on iteration numbers for leveling to reveal its significance and necessity on resource leveling. Best results of MS and P6 for fourty-five randomly selected resource overallocated projects in RCPSp were given in tables A-8 to A-13 for 30, 60, 120 activities in appendix part successively. Afterwards, results that are analyzed with t-test are given in tables 3-2 to 3-4.

Second comparision was between best results of MS and best results of P6 and aim was to know which software packages' resource leveling priority method is more successful. Comparision between best results of MS and best results of P6 for totally fourty-five randomly selected projects were given in tables A-14 to A-25 for 30, 60, 120 activities in appendix part successively. Afterwards, analyzed results with t-test are given in tables 3-11 to 3-13, 3-17 to 3-19, 3-23 to 3-25, and 3-29 to 3-31.

Third comparision was the best results of MS and P6 with the optimum and lower bound solutions. Comparision of optimum and lower bound solution results with best results of MS and P6 for totally fourty-five randomly selected projects were given in tables A-14 to A-25 for 30, 60, 120 activities in appendix part successively. Afterwards, analyzed results with t-test are given in tables 3-32 to 3-34. The percentage deviation of best results of MS and P6 solutions from optimum and lower bound solutions as benchmark will be shown

Fourth comparison was the best results of MS and P6 with the heuristic solutions. Comparison of the best results of MS and P6 with the heuristic solutions for totally forty-five randomly selected projects are given in tables A-29 to A-31 for 30, 60, 120 activities in appendix part successively. Afterwards, analyzed results with t-test are given in tables 3-32 to 3-34.

Finally, four comparison and their analyzed results with t-test are given in general evaluation part.

### **3.2 Comparison of P6 and MS Results Using t-test**

In this section, resource allocation capabilities of MS and P6 are compared for leveling priorities as determined in section 3.1 with successive iterations for 45 overallocated resource problems in RCPSP. P6 gives its users the chance to continue resource allocation successively for the proper leveling priorities. P6 gave same results, project completion time for different leveling priorities for some of the selected instances. For the same results, less iteration number, less successive leveling was the success criteria for leveling priority since it necessitated less effort. Then for the same results of P6, resource leveling priority with less iteration number accepted as more successful.

A paired sample t-test is used to determine whether there is a significant difference between the average values of the two populations, same measurement made under two different conditions. Both measurements are made on each unit in a sample, and the test is based on the paired differences between these two values. The usual null hypothesis is that the difference in the mean values is zero.

The null hypothesis for the paired sample t-test is

$$H_0: d = \mu_1 - \mu_2 = 0$$

where d is the mean value of the difference.

This null hypothesis is tested against one of the following alternative hypotheses, depending on the question posed:

H1:  $d > 0$

H1:  $d < 0$

The decision criteria for the t-test analysis is summarized in table 3-1.

### Interpreting the Paired t-test Results

Table 3-1: Paired t-test Acceptance

<b>If</b>	<b>Then</b>
test statistic > critical value (i.e. $t > t_{crit}$ )	Reject the null hypothesis
test statistic < critical value (i.e. $t < t_{crit}$ )	Accept the null hypothesis

Best results in resource allocation capabilities of P6 & MS as % for 30, 60 and 120 activities are given as first comparison in figures 3-1 to 3-3. P6 Leveling priorities gave 12 best results of 15 projects as ( 80 %) it is shown in figure 3-1 for projects with 30 activities.

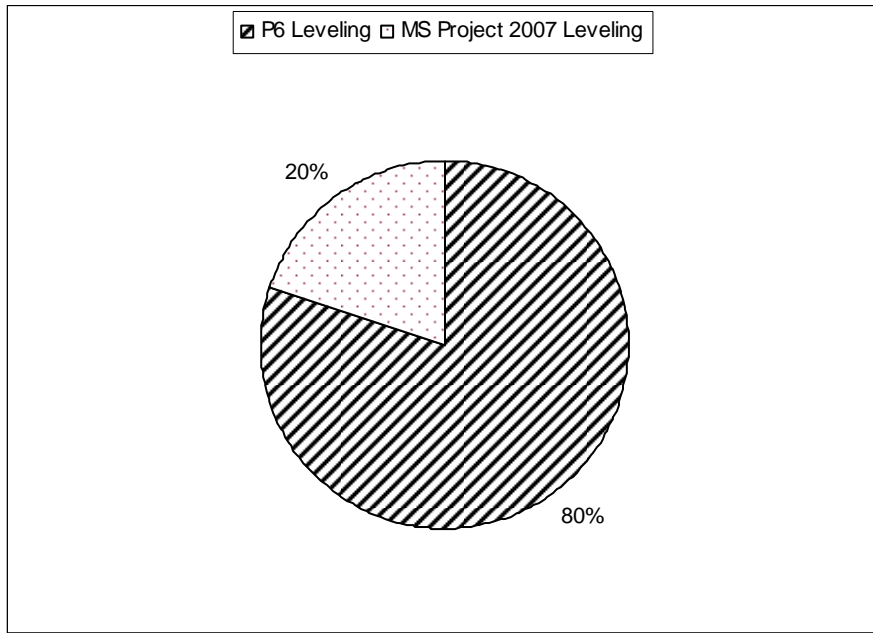


Figure 3-1: Best Results in Resource Allocation Capabilities of P6 & MS as % for 30 Activities

Details are given in tables A-8 and A-11 in appendix part. Then, it is claimed that  $\mu_1$  corresponding to MS results is greater than  $\mu_2$  corresponding to P6 results ( $\mu_1 > \mu_2$ ) for projects with 30 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

Analysis with t-test results for 30 activities are given in table 3-2. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.23) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations determined by P6 for the RCPS is better than the optimum durations of MS for projects with 30 activities.

Table 3-2: t-test: Paired Two Sample for Means Analysis for MS & P6 for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS</b>	<b>P6</b>
<b>Mean</b>	61	60
<b>Variance</b>	193,7143	171,8571
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>2,236068</b>	
<b>t Critical one-tail</b>	1,76131	

P6 Leveling priorities gave 10 best results over 15 projects as ( 67 %) it is shown in figure 3-2 for projects with 60 activities. Details are given in tables A-9 and A-12 in appendix part. Then, it is claimed that  $\mu_1$  corresponding to MS results is greater than  $\mu_2$  corresponding to P6 results ( $\mu_1 > \mu_2$ ) for projects with 60 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

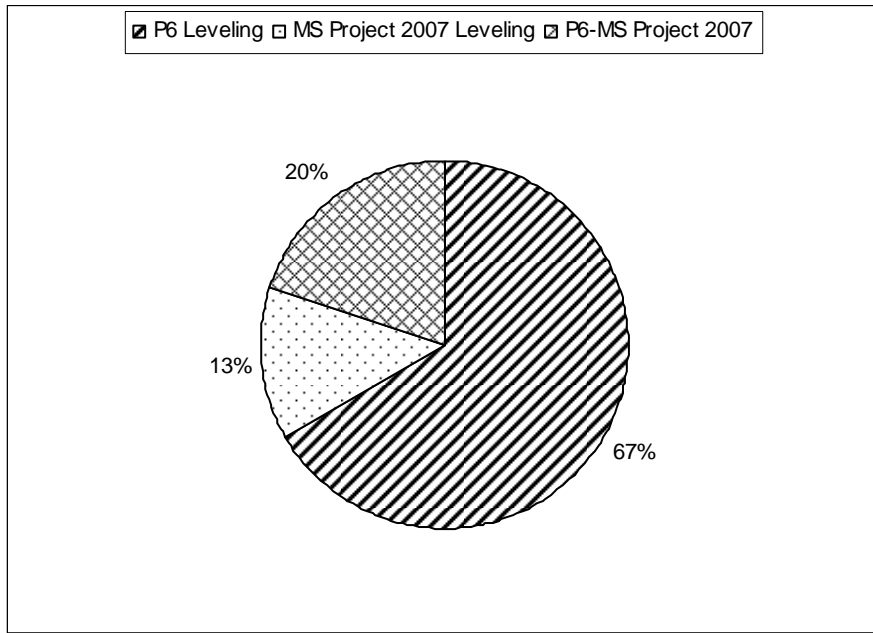


Figure 3-2: Best Results in Resource Allocation Capabilities of P6 & MS as % for 60 Activities

Analysis with t-test results for 60 activities are given in table 3-3. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.44) is larger than t critical (1.76).

Table 3-3: t-test: Paired Two Sample for Means Analysis for MS & P6 for 60 Activities

t-test: Paired Two Sample for Means	MS	P6
Mean	96,4	93,06667
Variance	906,2571	701,3524
Observations	15	15
Hypothesized Mean Difference	0	
df	14	
t Stat	<b>2,448091</b>	
t Critical one-tail	1,76131	

The result of the t-test indicate that the optimum durations determined by P6 for the RCPS P is better than the optimum durations of MS for projects with 60 activities.

P6 Leveling priorities gave 13 best results over 15 projects as ( 87 %) it is shown in figure 3-3 for projects with 60 activities. Details are given in tables A-10 and A-13 in appendix part. Then, it is claimed that  $\mu_1$  corresponding to MS results is greater than  $\mu_2$  corresponding to P6 results ( $\mu_1 > \mu_2$ ) for projects with 60 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

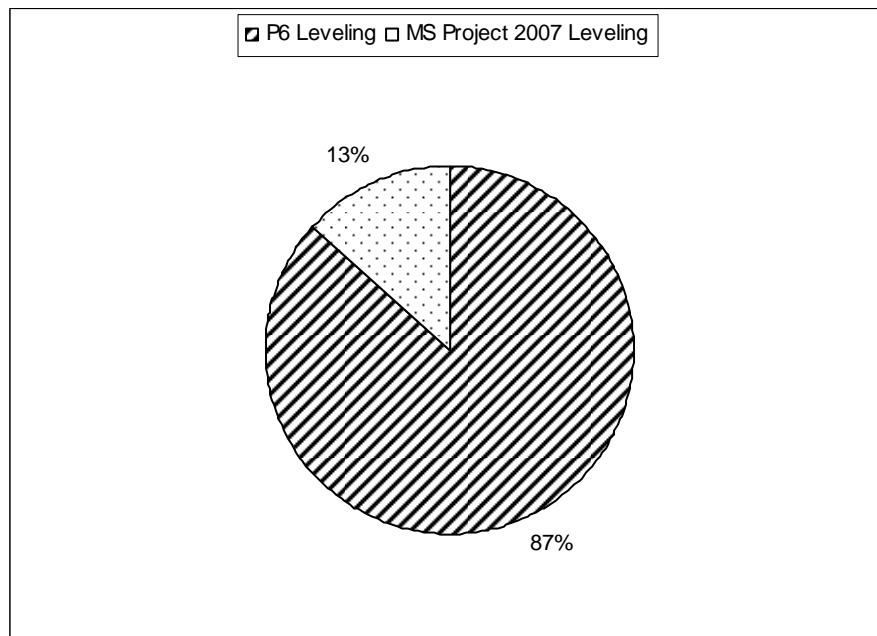


Figure 3-3: Best Results in Resource Allocation Capabilities of P6 & MS as % for 120 Activities

Analysis with t-test results for 120 activities are given in table 3-4. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.55) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations

determined by P6 for the RCPSP is better than the optimum durations of MS for projects with 120 activities.

Table 3-4: t-test: Paired Two Sample for Means Analysis for MS & P6 for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS</b>	<b>P6</b>
<b>Mean</b>	160,7333	142,6
<b>Variance</b>	4883,21	2558,971
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>2,551626</b>	
<b>t Critical one-tail</b>	1,76131	

Then, it is claimed that  $\mu_1$  corresponding to MS is greater than  $\mu_2$  corresponding to P6 ( $\mu_1 > \mu_2$ ) for 30, 60 and 120 activities.. We will reject the null hypothesis ( $H_0: d = \mu_1 - \mu_2 = 0$ ) if test statistic  $>$  critical value (i.e.  $t > t_{crit}$ ). This null hypothesis is tested against for the following alternative hypotheses, depending on our situation:

$$H_1: d > 0 (\mu_1 > \mu_2)$$

t-test is applied for best results of MS and P6.  $\alpha=0,05$  is used for paired t-test analysis, t-test:paired two sample for paired t-test analysis, which means  $100*(1-0,05) \% = 95 \%$  confidence interval for the paired data.

The values are successively shown below for test statistic  $>$  critical value;

$$\mathbf{30\ Activities} \rightarrow 2,236068 > 1,76131$$

$$\mathbf{60\ Activities} \rightarrow 2,448091 > 1,76131$$

$$\mathbf{120\ Activities} \rightarrow 2,551626 > 1,76131$$

Verified solution is that P6 is above board for  $J=30,60,120$  activities for resource leveling capability for resource constrained project scheduling problems within 95 % confidence interval based on paired data.

Second comparison is resource leveling priority methods within the software packages to know which leveling methodology is more successful for each package, MS and P6, successively in figures 3-4 to 3-15. Leveling priorities of MS as first part for second comparison is shown below;

MS-Standard leveling priority gave 11 best results over 15 projects as (69 %) it is shown in figure 3-4 for projects with 30 activities. Details are given in table A-14 in appendix part.. Then, it is claimed that  $\mu_1$  corresponding to MS-ID leveling priority results is greater than  $\mu_2$  corresponding to MS-Standard leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 30 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

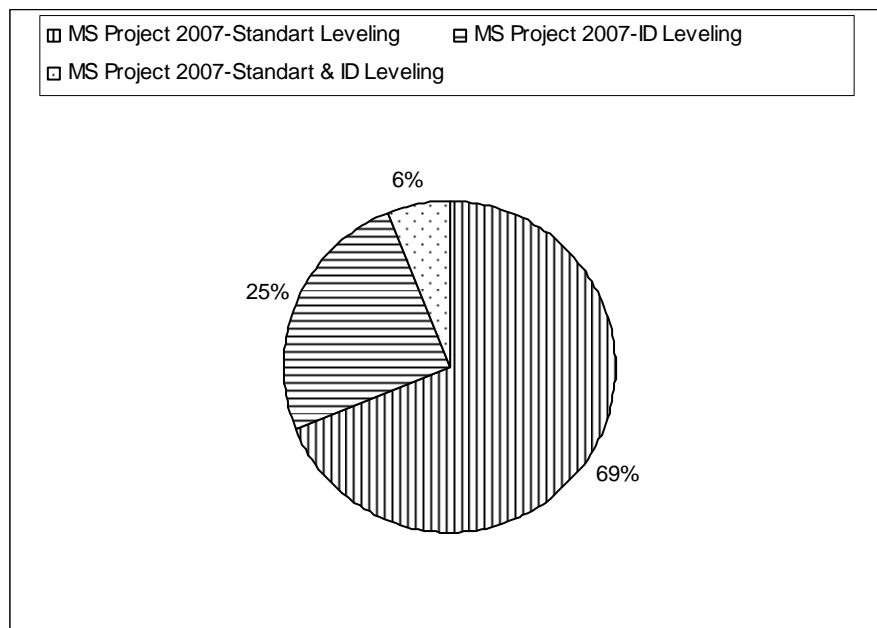


Figure 3-4: Success % of Resource Allocation Capabilities of MS Resource Leveling Priorities for 30 Activities

Analysis with t-test results for 30 activities are given in table 3-5. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.53) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations determined by MS-Standart for the RCPSP is better than MS-ID for projects with 30 activities.

Table 3-5: t-test: Paired Two Sample for Means Analysis for MS ID & MS Standart for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS ID</b>	<b>MS Standart</b>
<b>Mean</b>	65,6	61,53333
<b>Variance</b>	222,2571	197,8381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>2,529152</b>	
<b>t Critical one-tail</b>	1,76131	

MS-Standart leveling priority gave 13 best results over 15 projects as (87 %) it is shown in figure 3-5 for projects with 60 activities. Details are given in table A-15 in appendix part.. Then, it is claimed that  $\mu_1$  corresponding to MS-ID leveling priority results is greater than  $\mu_2$  corresponding to MS-Standart leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 60 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

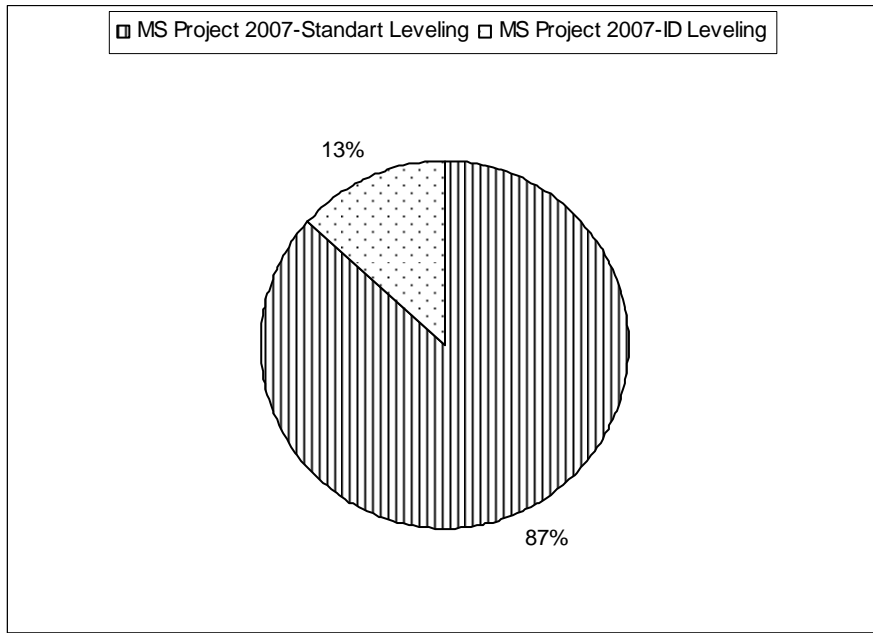


Figure 3-5: Success % of Resource Allocation Capabilities of MS Resource Leveling Priorities for 60 Activities

Analysis with t-test results for 60 activities are given in table 3-6. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (4.17) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations determined by MS-Standard for the RCPSP is better than MS-ID for projects with 60 activities.

Table 3-6: t-test: Paired Two Sample for Means Analysis for MS ID & MS Standard for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS ID</b>	<b>MS Standard</b>
<b>Mean</b>	104,1333	96,66667
<b>Variance</b>	933,981	930,5238
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>4,168621</b>	
<b>t Critical one-tail</b>	1,76131	

MS-Standard leveling priority gave 11 best results over 15 projects as (73 %) it is shown in figure 3-6 for projects with 120 activities. Details are given in table A-16 in appendix part.. Then, it is claimed that  $\mu_1$  corresponding to MS-ID leveling priority results is greater than  $\mu_2$  corresponding to MS-Standard leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 120 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

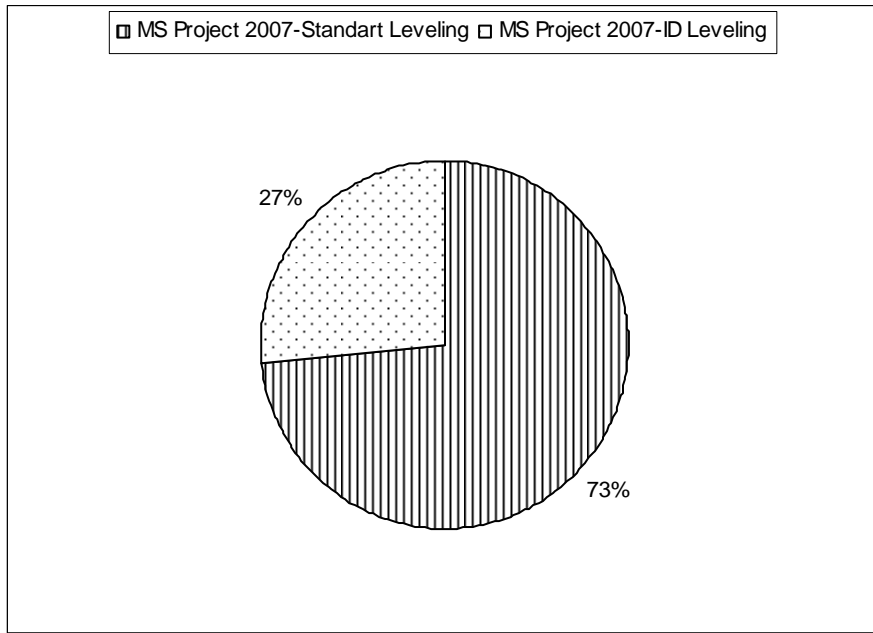


Figure 3-6: Success % of Resource Allocation Capabilities of MS Resource Leveling Priorities for 120 Activities

Analysis with t-test results for 120 activities are given in table 3-7. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.81) is larger than t critical (1.76).

Table 3-7: t-test: Paired Two Sample for Means Analysis for MS ID & MS Standard for 120 Activities

t-test: Paired Two Sample for Means	MS ID	MS Standart
Mean	170,5333	163,2667
Variance	4756,124	4675,638
Observations	15	15
Hypothesized Mean Difference	0	
df	14	
t Stat	<b>2,805431</b>	
t Critical one-tail	1,76131	

The result of the t-test indicate that the optimum durations determined by MS-Standard for the RCPSP is better than MS-ID for projects with 120 activities.

The results indicate that MS-Standard provides better results than MS-ID for the RCPSP for 30, 60 and 120 activities. To test the significance of the difference between MS-Standard and MS-ID t-test was used. Corresponding t-test results are given in tables 3-5 to 3-7.

Then, it is claimed that  $\mu_1$  corresponding to MS-ID results is greater than  $\mu_2$  corresponding to MS-Standard results ( $\mu_1 > \mu_2$ ) for 30, 60 and 120 activities.. We will reject the null hypothesis ( $H_0: d = \mu_1 - \mu_2 = 0$ ) if test statistic  $>$  critical value (i.e.  $t > t_{crit}$ ). This null hypothesis is tested against for the following alternative hypotheses, depending on our situation:

$$H_1: d > 0 (\mu_1 > \mu_2)$$

t-test is applied for results of MS-ID and MS-Standard.  $\alpha=0,05$  is used for paired t-test analysis, t-test : paired two sample for paired t-test analysis, which means  $100*(1-0,05) \% = 95 \%$  confidence interval for the paired data.

The values are successively shown below for test statistic  $>$  critical value;

$$\mathbf{30\ Activities} \rightarrow 2,529152 > 1,76131$$

$$\mathbf{60\ Activities} \rightarrow 4,168621 > 1,76131$$

$$\mathbf{120\ Activities} \rightarrow 2,805431 > 1,76131$$

Verified solution is that Standard leveling priority for MS Project 2007 is above board for J=30,60,120 activities for resource Leveling capability for resource constrained project scheduling problems within 95 % confidence interval based on paired data.

After analyzing the MS, the next comparison is for resource leveling priority methods of P6 to know which leveling methodology is more successful for P6. There will be three comparison analysis for P6 as shown below;

1. P6 Default between Best Results of P6 Total Float (TF) (minimum makespan with its 10 consecutive iterations)
2. P6 Default between Best Results of P6 Late Finish Time (LFT) (minimum makespan with its 2 consecutive iterations)
3. Best Results of P6 LFT (minimum makespan with its 2 consecutive iterations) between Best Results of P6 TF (minimum makespan with its 10 consecutive iterations)

P6 TF leveling priority gave 10 best results over 15 projects as (67 %) it is shown in figure 3-7 for projects with 30 activities. Details are given in table A-17 in appendix part. Then, it is claimed that  $\mu_1$  corresponding to P6-Default leveling priority results is greater than  $\mu_2$  corresponding to P6-TF leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 30 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods..

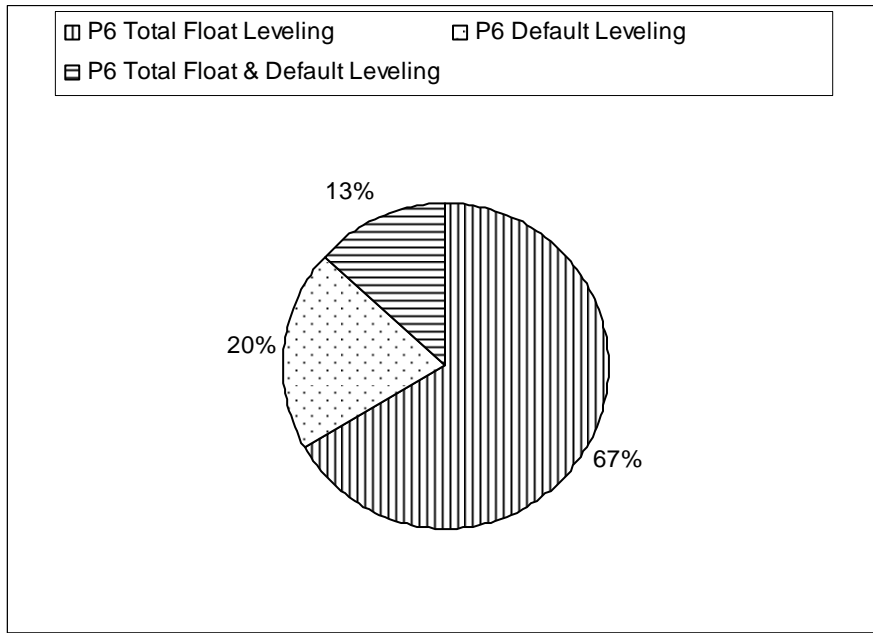


Figure 3-7: Success % of Resource Allocation Capabilities of P6 Default & P6 TF for 30 Activities

Analysis with t-test results for 30 activities are given in table 3-8.

Table 3-8: t-test: Paired Two Sample for Means Analysis for P6 Default & Best Results of P6 Total Float with 10 consecutive iteration for 30 Activities

t-test: Paired Two Sample for Means	P6 Default	P6 TF
Mean	66,2	61,06666667
Variance	264,4571429	172,4952381
Observations	15	15
Hypothesized Mean Difference	0	
df	14	
t Stat	<b>2,588744595</b>	
t Critical one-tail	1,761310115	

The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.59)

is larger than t critical (1.76). The result of the t-test indicate that the optimum durations determined by P6-TF for the RCPSP is better than P6-Default for projects with 30 activities.

P6 TF leveling priority gave 13 best results over 15 projects as (86 %) it is shown in figure 3-8 for projects with 60 activities. Details are given in table A-18 in appendix part.. Then, it is claimed that  $\mu_1$  corresponding to P6-Default leveling priority results is greater than  $\mu_2$  corresponding to P6-TF leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 60 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

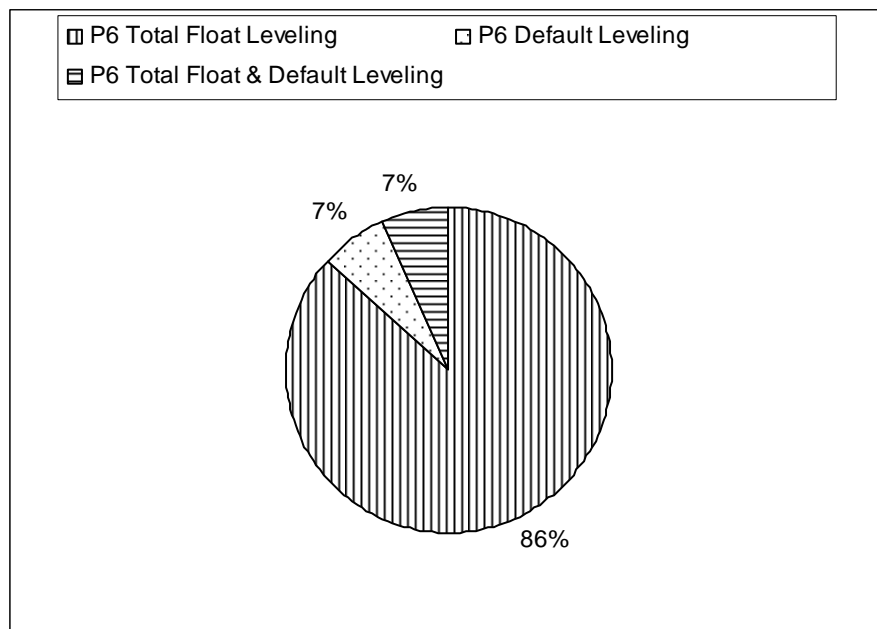


Figure 3-8: Success % of Resource Allocation Capabilities of P6 Default & P6 TF for 60 Activities

Analysis with t-test results for 60 activities are given in table 3-9. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (5.77) is larger

than t critical (1.76). The result of the t-test indicate that the optimum durations determined by P6-TF for the RCPSP is better than P6-Default for projects with 60 activities.

Table 3-9: t-test: Paired Two Sample for Means Analysis for P6 Default & Best Results of P6 Total Float with 10 consecutive iteration for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 Default</b>	<b>P6 TF</b>
<b>Mean</b>	103,1333333	95
<b>Variance</b>	724,2666667	749,2857143
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>5,766717188</b>	
<b>t Critical one-tail</b>	1,761310115	

P6 TF leveling priority gave 11 best results over 15 projects as it is shown in figure 3-9 as 73 % for projects with 120 activities. Details are given in table A-19 in appendix part. Then, it is claimed that  $\mu_1$  corresponding to P6-Default leveling priority results is greater than  $\mu_2$  corresponding to P6-TF leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 60 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

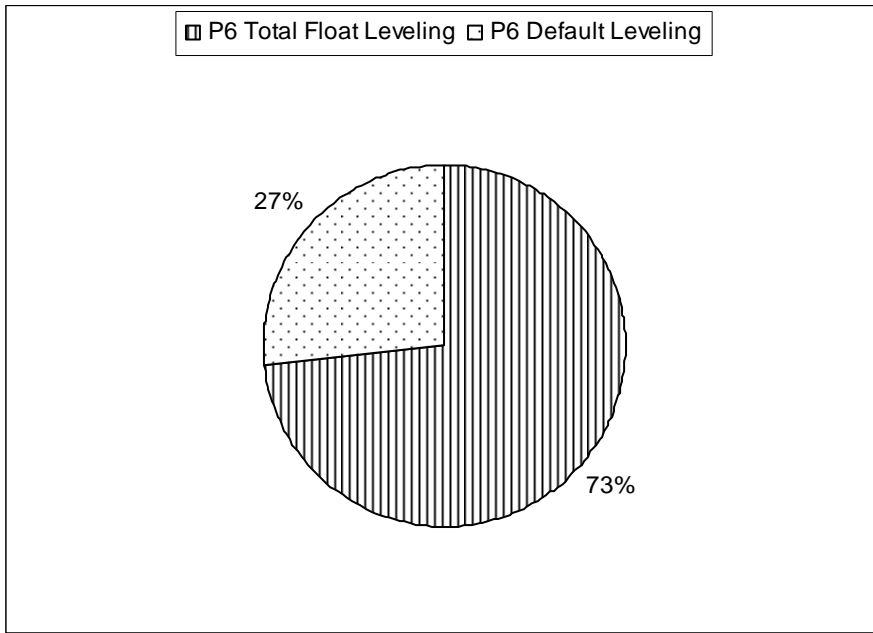


Figure 3-9: Success % of Resource Allocation Capabilities of P6 Default & P6 TF for 120 Activities

Analysis with t-test results for 120 activities are given in table 3-10.

Table 3-10: t-test: Paired Two Sample for Means Analysis for P6 Default & Best Results of P6 Total Float with 10 consecutive iteration for 120 Activities

t-test: Paired Two Sample for Means	P6 Default	P6 TF
Mean	154,8666667	148,4666667
Variance	2442,409524	2956,266667
Observations	15	15
Hypothesized Mean Difference	0	
df	14	
t Stat	<b>3,92760893</b>	
t Critical one-tail	1,761310115	

The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (3.93) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations determined by P6-TF for the RCPSP is better than P6-Default for projects with 120 activities.

The results indicate that P6-TF leveling priority provides better results than P6-Default for the RCPSP for 30, 60 and 120 activities. To test the significance of the difference between P6-TF and P6-Default t-test was used. Corresponding t-test results are given in tables 3-8 to 3-10.

Then, it is claimed that  $\mu_1$  corresponding to P6-Default results is greater than  $\mu_2$  corresponding to P6-TF results ( $\mu_1 > \mu_2$ ) for 30, 60 and 120 activities.. We will reject the null hypothesis ( $H_0: d = \mu_1 - \mu_2 = 0$ ) if test statistic  $>$  critical value (i.e.  $t > t_{crit}$ ). This null hypothesis is tested against for the following alternative hypotheses, depending on our situation:

$$H_1: d > 0 (\mu_1 > \mu_2)$$

t-test is applied for results of P6-TF and P6-Default.  $\alpha=0,05$  is used for paired t-test analysis, t-test:paired two sample for paired t-test analysis, which means  $100*(1-0,05) \% = 95 \%$  confidence interval for the paired data.

The values are successively shown below for test statistic  $>$  critical value;

$$\mathbf{30 Activities} \rightarrow 2,588744595 > 1,76131$$

$$\mathbf{60 Activities} \rightarrow 5,766717188 > 1,76131$$

$$\mathbf{120 Activities} \rightarrow 3,92760893 > 1,76131$$

Verified solution is that Total Float leveling priority for P6 is above board against P6-Default for  $J=30,60,120$  activities for resource Leveling capability for resource

constrained project scheduling problems within 95 % confidence interval based on paired data.

P6 LFT leveling priority gave 10 best results over 15 projects (67 %) it is shown in figure 3-10 for projects with 30 activities. Details are given in table A-20 in appendix part.. Then, it is claimed that  $\mu_1$  corresponding to P6-Default leveling priority results is greater than  $\mu_2$  corresponding to P6-LFT leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 30 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

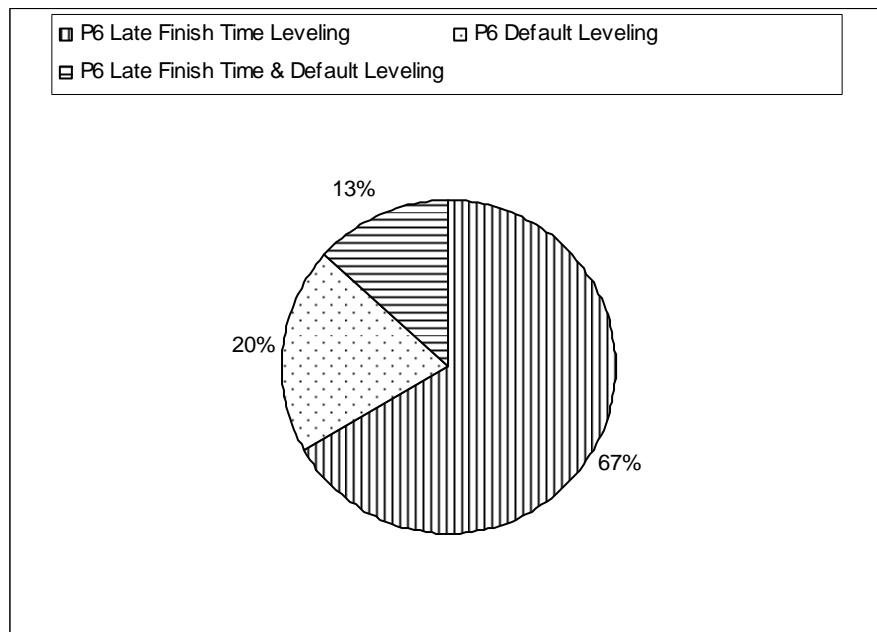


Figure 3-10: Success % of Resource Allocation Capabilities of P6 Default & P6 LFT for 30 Activities

Analysis with t-test results for 30 activities are given in table 3-11. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.05) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations

determined by P6-LFT for the RCPSP is better than P6-Default for projects with 30 activities.

Table 3-11: t-test: Paired Two Sample for Means Analysis for P6 Default & Best Results of P6 LFT with 2 consecutive iterations for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 Default</b>	<b>P6 LFT</b>
<b>Mean</b>	66,2	62,93333333
<b>Variance</b>	264,4571429	195,7809524
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>2,04674924</b>	
<b>t Critical one-tail</b>	1,761310115	

P6 LFT leveling priority gave 13 best results over 15 projects as it is shown in figure 3-11 as 87 % for projects with 60 activities. Details are given in table A-21 in appendix part. Then, it is claimed that  $\mu_1$  corresponding to P6-Default leveling priority results is greater than  $\mu_2$  corresponding to P6-LFT leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 60 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

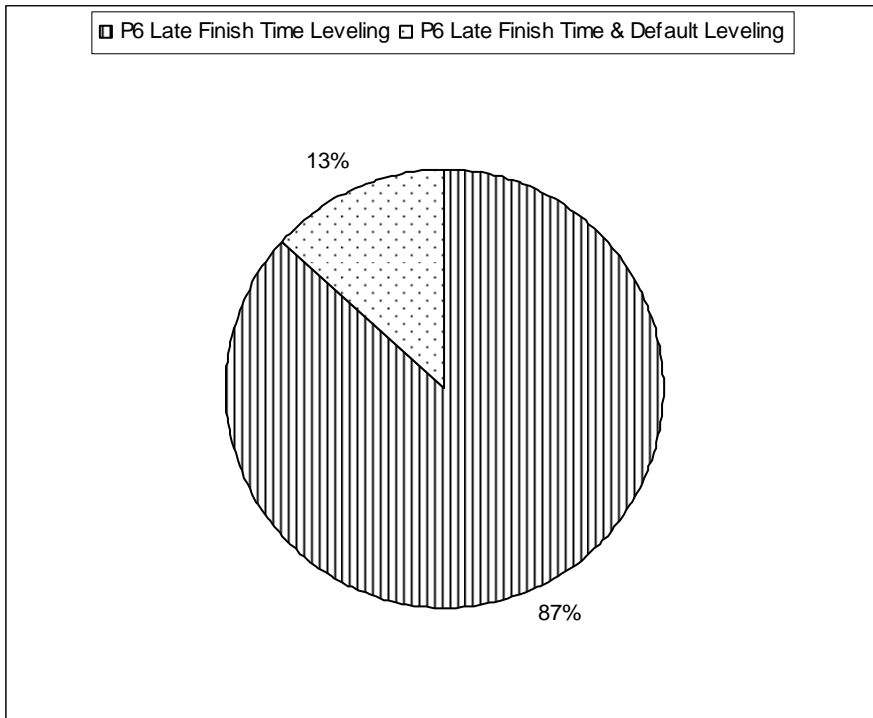


Figure 3-11: Success % of Resource Allocation Capabilities of P6 Default & P6 LFT for 60 Activities

Analysis with t-test results for 60 activities are given in table 3-12.

Table 3-12: t-test: Paired Two Sample for Means Analysis for P6 Default & Best Results of P6 LFT with 2 consecutive iterations for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 Default</b>	<b>P6 LFT</b>
<b>Mean</b>	103,1333333	93,53333333
<b>Variance</b>	724,2666667	724,4095238
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>5,923368502</b>	
<b>t Critical one-tail</b>	1,761310115	

The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (5.92) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations determined by P6-LFT for the RCPSP is better than P6-Default for projects with 60 activities.

P6 LFT leveling priority gave 15 best results over 15 projects as it is shown in figure 3-12 as 100 % for projects with 120 activities. Details are given in table A-22 in appendix part.. Then, it is claimed that  $\mu_1$  corresponding to P6-Default leveling priority results is greater than  $\mu_2$  corresponding to P6-LFT leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 120 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

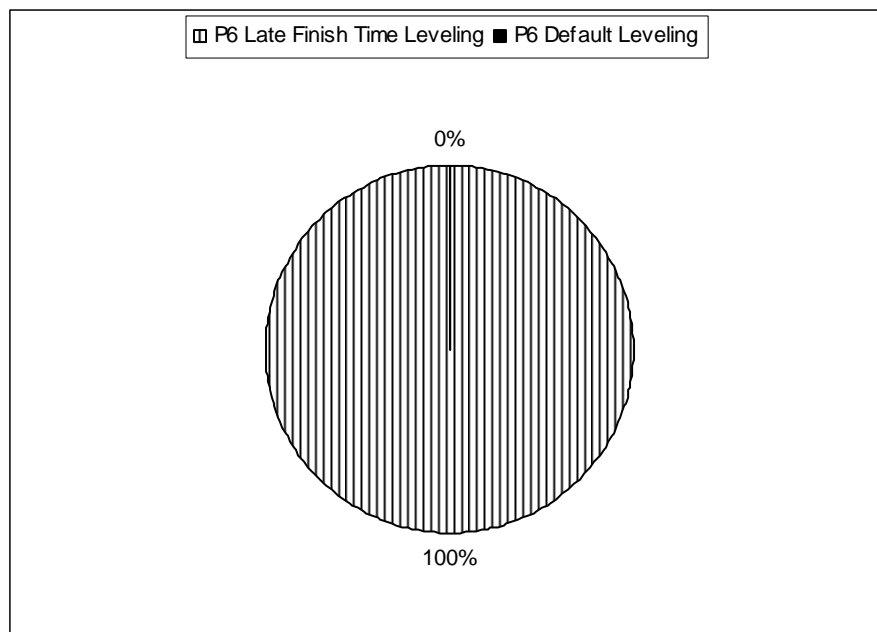


Figure 3-12: Success % of Resource Allocation Capabilities of P6 Default & P6 LFT for 120 Activities

Analysis with t-test results for 120 activities are given in table 3-13. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (15.11) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations determined by P6-LFT for the RCPSP is better than P6-Default for projects with 120 activities.

Table 3-13: t-test: Paired Two Sample for Means Analysis for P6 Default between Best Results of P6 LFT with 2 consecutive iterations for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 Default</b>	<b>P6 LFT</b>
<b>Mean</b>	154,8666667	142,9333333
<b>Variance</b>	2442,409524	2540,92381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>15,11284775</b>	
<b>t Critical one-tail</b>	1,761310115	

The results indicate that P6-LFT leveling priority provides better results than P6-Default for the RCPSP for 30, 60 and 120 activities. To test the significance of the difference between P6-LFT and P6-Default t-test was used. Corresponding t-test results are given in tables 3-11 to 3-13.

Then, it is claimed that  $\mu_1$  corresponding to P6-Default results is greater than  $\mu_2$  corresponding to P6-LFT results ( $\mu_1 > \mu_2$ ) for 30, 60 and 120 activities.. We will reject the null hypothesis ( $H_0: d = \mu_1 - \mu_2 = 0$ ) if test statistic  $>$  critical value (i.e.  $t > t_{crit}$ ). This null hypothesis is tested against for the following alternative hypotheses, depending on our situation:

$$H_1: d > 0 (\mu_1 > \mu_2)$$

t-test is applied for results of P6-LFT and P6-Default.  $\alpha=0,05$  is used for paired t-test analysis, t-test:paired two sample for paired t-test analysis, which means  $100*(1-0,05) \% = 95 \%$  confidence interval for the paired data.

The values are successively shown below for test statistic  $>$  critical value;

**30 Activities**  $\rightarrow$  2,04674924  $>$  1,76131

**60 Activities**  $\rightarrow$  5,923368502  $>$  1,76131

**120 Activities**  $\rightarrow$  15,11284775  $>$  1,76131

Verified solution is that Late Finish Time leveling priority for P6 is above board against P6-Default for  $J=30,60,120$  activities for resource Leveling capability for resource constrained project scheduling problems within 95 % confidence interval based on paired data.

P6 TF leveling priority gave 7 best results over 15 projects as (47 %) it is shown in figure 3-13 for projects with 30 activities. Details are given in table A-23 in appendix part. Then, it is claimed that  $\mu_1$  corresponding to P6-LFT leveling priority results is greater than  $\mu_2$  corresponding to P6-TF leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 30 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

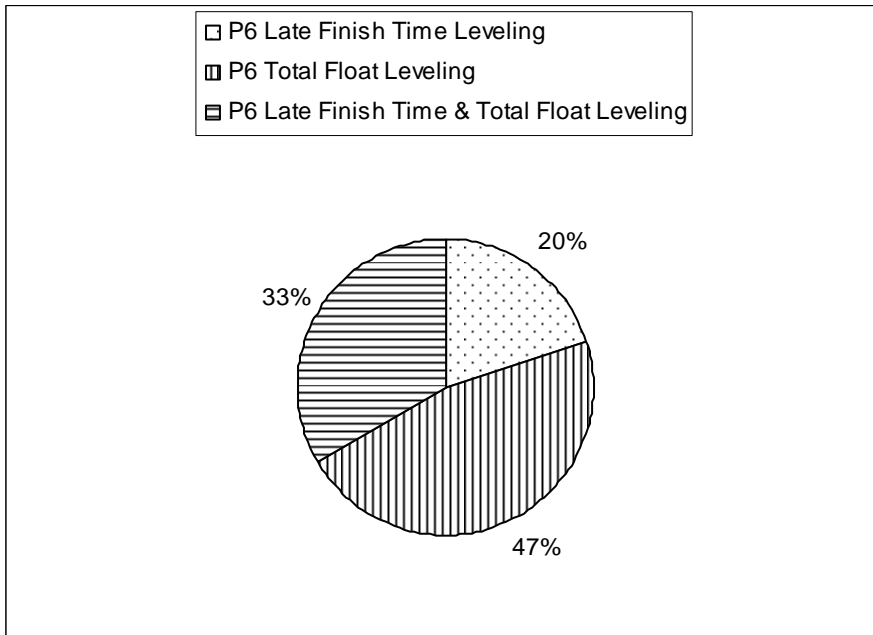


Figure 3-13: Success % of Resource Allocation Capabilities of P6 LFT & P6 TF for 30 Activities

Analysis with t-test results for 30 activities are given in table 3-14.

Table 3-14: t-test: Paired Two Sample for Means Analysis for Best Results of P6 TF with 10 consecutive iterations & P6 LFT with 2 consecutive iterations for 30 Activities

t-test: Paired Two Sample for Means	P6 LFT	P6 TF
Mean	61,06666667	62,93333333
Variance	172,4952381	195,7809524
Observations	15	15
Hypothesized Mean Difference	0	
df	14	
t Stat	<b>1,72561689</b>	
t Critical one-tail	1,761310115	

The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is rejected since t stat (1.73) is smaller than t critical (1.76). The result of the t-test indicate that the optimum durations determined by P6-TF for the RCPSP is not better than P6-LFT for projects with 30 activities.

P6 LFT leveling priority gave 8 best results over 15 projects as (53 %) it is shown in figure 3-14 for projects with 60 activities. Details are given in table A-24 in appendix part.. Then, it is claimed that  $\mu_1$  corresponding to P6-TF leveling priority results is greater than  $\mu_2$  corresponding to P6-LFT leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 60 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

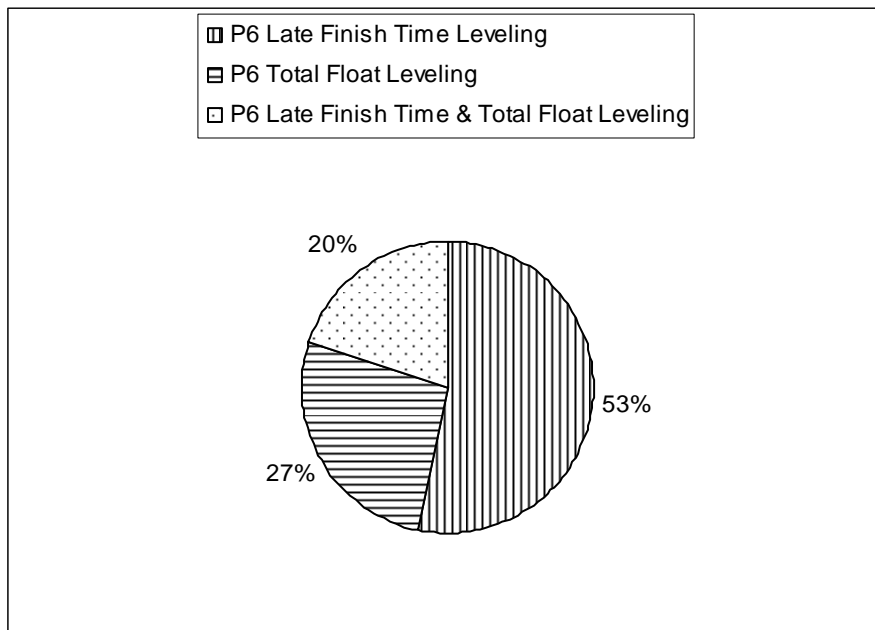


Figure 3-14: Success % of Resource Allocation Capabilities of P6 LFT & P6 TF for 60 Activities

Analysis with t-test results for 60 activities are given in table 3-15. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected

and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (1.78) is larger than t critical (1.76). The result of the t-test indicate that the optimum durations determined by P6-LFT for the RCPSP is better than P6-TF for projects with 60 activities.

Table 3-15: t-test: Paired Two Sample for Means Analysis for Best Results of P6 TF with 10 consecutive iterations & P6 LFT with 2 consecutive iterations for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 TF</b>	<b>P6 LFT</b>
<b>Mean</b>	95	93,53333333
<b>Variance</b>	749,2857143	724,4095238
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1,785274775</b>	
<b>t Critical one-tail</b>	1,761310115	

P6 LFT leveling priority gave 11 best results over 15 projects as it is shown in figure 3-15 as 73 % for projects with 120 activities. Details are given in table A-25 in appendix part.. Then, it is claimed that  $\mu_1$  corresponding to P6-TF leveling priority results is greater than  $\mu_2$  corresponding to P6-LFT leveling priority results ( $\mu_1 > \mu_2$ ) for projects with 120 activities. To verify this claim, it is necessary to analyze for the entire population with statistical methods.

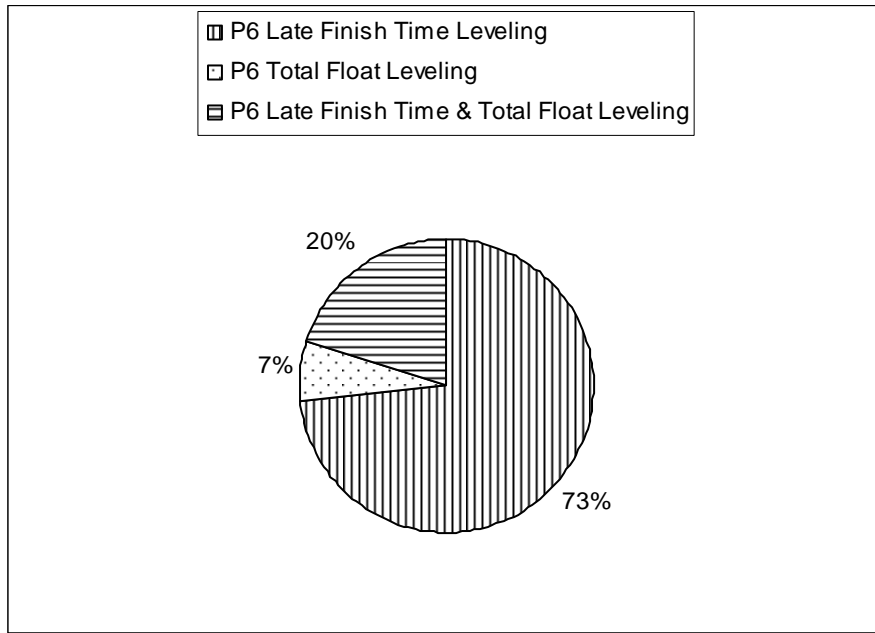


Figure 3-15: Success % of Resource Allocation Capabilities of P6 LFT & P6 TF for 120 Activities

Analysis with t-test results for 120 activities are given in table 3-16. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (3.77) is larger than t critical (1.76).

Table 3-16: t-test: Paired Two Sample for Means Analysis for Best Results of P6 TF with 10 consecutive iterations & P6 LFT with 2 consecutive iterations for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 TF</b>	<b>P6 LFT</b>
<b>Mean</b>	149,6666667	143,8666667
<b>Variance</b>	2824,952381	2446,12381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>3,772434905</b>	
<b>t Critical one-tail</b>	1,761310115	

The result of the t-test indicate that the optimum durations determined by P6-LFT for the RCPSP is better than P6-TF for projects with 120 activities.

The results indicate that P6-TF leveling priority provides better results than P6-LFT for the RCPSP for 30 activities. To test the significance of the difference between P6-LFT and P6-TF, t-test was used. Corresponding t-test results are given in table 3-14. This null hypothesis is tested against for the following alternative hypotheses, depending on our situation:

$$H1: d > 0 (\mu_1 > \mu_2)$$

t-test is applied for results of P6-LFT and P6-Default.  $\alpha=0,05$  is used for paired t-test analysis, t-test:paired two sample for paired t-test analysis, which means  $100*(1-0,05) \% = 95 \%$  confidence interval for the paired data.

Then, it is claimed that  $\mu_1$  corresponding to P6-LFT results is greater than  $\mu_2$  corresponding to P6-TF results ( $\mu_1 > \mu_2$ ) for 30 activities. We will reject the null hypothesis ( $H_0: d = \mu_1 - \mu_2 = 0$ ) if test statistic  $>$  critical value (i.e.  $t > t_{crit}$ ).

The results indicate that P6-LFT leveling priority provides better results than P6-TF for the RCPSP for 60 and 120 activities. To test the significance of the difference between P6-LFT and P6-TF, t-test was used. Corresponding t-test results are given in tables 3-15 and 3-16. This null hypothesis is tested against for the following alternative hypotheses, depending on our situation:

$$H1: d > 0 (\mu_1 > \mu_2)$$

t-test is applied for results of P6-LFT and P6-Default.  $\alpha=0,05$  is used for paired t-test analysis, t-test:paired two sample for paired t-test analysis, which means  $100*(1-0,05) \% = 95 \%$  confidence interval for the paired data.

The values are successively shown below for test statistic  $<$  critical value;

**30 Activities** →  $1,72561689 < 1,76131$

Verified solution is that Total Float leveling priority for P6 is not above board against P6-LFT for J=30 activities for resource leveling capability for resource constrained project scheduling problems within 95 % confidence interval based on paired data.

The values are successively shown below for test statistic > critical value;

**60 Activities** →  $1,785274775 > 1,76131$

**120 Activities** →  $3,772434905 > 1,76131$

Verified solution is that Late Finish Time leveling priority for P6 is above board against P6-Default for J=60,120 activities for resource leveling capability for resource constrained project scheduling problems within 95 % confidence interval based on paired data.

After examining the results above we consider five more analysis are required as below;

1. Best Results of MS between MS Standart
2. Best Results of P6 between Best Results of P6 LFT
3. Best Results of P6 between Best Results of P6 TF
4. Best Results of P6 TF between MS-Standart
5. Best Results of P6 LFT between MS-Standart

It is considered that there is a significant difference between mean values of Best Results of MS and MS Standart. To verify this claim the following t-test was used.

Analysis with t-test results for 30 activities are given in table 3-17. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is rejected since t stat (1.52) is smaller than t critical (1.76). The result of the t-test indicate that the mean difference between MS Standart and Best Results of MS are not significant. Two samples are not different for projects with 30 activities.

Table 3-17: t-test: Paired Two Sample for Means Analysis for Best Results of MS & MS Standart for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS Standart</b>	<b>Best of MS</b>
<b>Mean</b>	61,53333333	61
<b>Variance</b>	197,8380952	193,7142857
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1,523562773</b>	
<b>t Critical one-tail</b>	1,761310115	

Analysis with t-test results for 60 activities are given in table 3-18. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is rejected since t stat (1.29) is smaller than t critical (1.76). The result of the t-test indicate that the mean difference between MS Standart and Best Results of MS are not significant. Two samples are not different for projects with 60 activities.

Table 3-18: t-test: Paired Two Sample for Means Analysis for Best Results of MS & MS Standart for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS Standart</b>	<b>Best of MS</b>
<b>Mean</b>	96,66666667	96,4
<b>Variance</b>	930,5238095	906,2571429
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1,29291987</b>	
<b>t Critical one-tail</b>	1,761310115	

Analysis with t-test results for 120 activities are given in table 3-19. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is rejected since t stat (1.59) is smaller than t critical (1.76). The result of the t-test indicate that the mean difference between MS Standart and Best Results of MS are not significant. Two samples are not different for projects with 120 activities.

Table 3-19: t-test: Paired Two Sample for Means Analysis for Best Results of MS & MS Standart for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS Standart</b>	<b>Best of MS</b>
<b>Mean</b>	163,2666667	162,1333333
<b>Variance</b>	4675,638095	4751,409524
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1,597207525</b>	
<b>t Critical one-tail</b>	1,761310115	

The values are successively shown below for test statistic > critical value;

**30 Activities** → 1,523562773 < 1,76131

**60 Activities** → 1,29291987 < 1,76131

**120 Activities** → 1,597207525 < 1,76131

Verified solution is that the mean difference between MS Standart and best results of MS are not significant J=30,60,120. Two samples are not different for J=30,60,120.

It is considered that there is a significant difference between mean values of best results of P6 between best results of P6 LFT. Details are given for projects with 30, 60 and 120 activities in table A-32 to A-34 in appendix part successively. To verify this claim the following t-test was used.

Analysis with t-test results for 30 activities are given in table 3-20. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.57) is larger than t critical (1.76).

Table 3-20: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & P6 LFT for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 LFT</b>	<b>Best of P6</b>
<b>Mean</b>	62,93333	60,06667
<b>Variance</b>	195,781	172,2095
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>2,567777</b>	
<b>t Critical one-tail</b>	1,76131	

The result of the t-test indicate that the mean difference between mean values of best results of P6 between best results of P6 LFT are significant for projects with 30

activities. P6 LFT is not the optimum solution as best results of P6 for projects with 30 activities.

Analysis with t-test results for 60 activities are given in table 3-21. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is rejected since t stat (1.70) is smaller than t critical (1.76).

The result of the t-test indicate that the mean difference between mean values of best results of P6 between best results of P6 LFT are not significant for projects with 60 activities. Two samples are not different as best results of P6 for projects with 60 activities.

Table 3-21: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & P6 LFT for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 LFT</b>	<b>Best of P6</b>
<b>Mean</b>	93,53333	93,06667
<b>Variance</b>	724,4095	701,3524
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1,704928</b>	
<b>t Critical one-tail</b>	1,76131	

Analysis with t-test results for 120 activities are given in table 3-22. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is rejected since t stat (1) is smaller than t critical (1.76).

Table 3-22: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & P6 LFT for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 LFT</b>	<b>Best of P6</b>
<b>Mean</b>	143,8667	143,5333
<b>Variance</b>	2446,124	2464,838
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1</b>	
<b>t Critical one-tail</b>	1,76131	

The result of the t-test indicate that the mean difference between mean values of best results of P6 between best results of P6 LFT are not significant for projects with 120 activities. Two samples are not different as best results of P6 for projects with 120 activities.

The values are successively shown below for test statistic > critical value;

**30 Activities** → 2,567777 > 1,76131

**60 Activities** → 1,704928 < 1,76131

**120 Activities** → 1 < 1,76131

There is a significant difference between Best Results of P6 LFT and Best Results of P6 for 30 activities. In conclusion, it should be investigated for better results with P6 Default and P6 TF for 30 activities.

There is not a significant difference between Best Results of P6 LFT and Best Results of P6 for J=60,120 activities for resource allocation capability for resource constrained project scheduling problems. In conclusion, it will be sufficient to

examine P6 LFT priority with consecutive 2 iterations for P6 users for J=60,120 activities for resource allocation capability for resource constrained projects.

It is considered that there is a significant difference between mean values of best results of P6 between best results of P6 TF. Details are given for projects with 30, 60 and 120 activities in table A-35 to A-37 in appendix part successively. To verify this claim the following t-test was used.

Analysis with t-test results for 30 activities are given in table 3-23. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is accepted since t stat (1.94) is larger than t critical (1.76).

Table 3-23: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & P6 TF for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 TF</b>	<b>Best of P6</b>
<b>Mean</b>	61,06666667	60,06666667
<b>Variance</b>	172,4952381	172,2095238
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1,936491673</b>	
<b>t Critical one-tail</b>	1,761310115	

The result of the t-test indicate that the difference between mean values of best results of P6 and best results of P6 TF are significant for projects with 30 activities. P6 TF is not the optimum solution as best results of P6 for projects with 30 activities.

Analysis with t-test results for 60 activities are given in table 3-24. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is accepted since t stat (2.82) is larger than t critical (1.76). The result of the t-test indicate that the difference between

mean values of best results of P6 and best results of P6 TF are significant for projects with 60 activities. P6 TF is not the optimum solution as best results of P6 for projects with 60 activities.

Table 3-24: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & P6 TF for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 TF</b>	<b>Best of P6</b>
<b>Mean</b>	95	93,06666667
<b>Variance</b>	749,2857143	701,352381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>2,816729001</b>	
<b>t Critical one-tail</b>	1,761310115	

Analysis with t-test results for 120 activities are given in table 3-25. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (4.38) is larger than t critical (1.76).

Table 3-25: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & P6 TF for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>P6 TF</b>	<b>Best of P6</b>
<b>Mean</b>	149,66666667	143,53333333
<b>Variance</b>	2824,952381	2464,838095
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>4,380242972</b>	
<b>t Critical one-tail</b>	1,761310115	

The result of the t-test indicate that the difference between mean values of best results of P6 and best results of P6 TF are significant for projects with 120 activities. P6 TF is not the optimum solution as best results of P6 for projects with 120 activities.

The values are successively summarized below for test statistic > critical value;

**30 Activities** → 1,936491673 > 1,76131

**60 Activities** → 2,816729001 > 1,76131

**120 Activities** → 4,380242972 > 1,76131

There is a significant difference between Best Results of P6 TF and Best Results of P6 for 30, 60 and 120 activities for resource allocation capability for resource constrained project scheduling problems. In conclusion, it should be investigated for better results with P6 Default and P6 LFT for 30 activities, 60 and 120 activities.

It is considered that there is a significant difference between mean values of MS-Standard and best results of P6 TF. Details are given for projects with 30, 60 and 120 activities in table A-38 to A-40 in appendix part successively. To verify this claim the following t-test was used.

Analysis with t-test results for 30 activities are given in table 3-26. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is rejected since t stat (0.75) is smaller than t critical (1.76).

Table 3-26: t-test: Paired Two Sample for Means Analysis for Best Results of P6 TF & MS Standart for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS Standart</b>	<b>P6 TF</b>
<b>Mean</b>	61,53333333	61,06666667
<b>Variance</b>	197,8380952	172,4952381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>0,748026223</b>	
<b>t Critical one-tail</b>	1,761310115	

The result of the t-test indicate that the difference between mean values of MS-Standart and best results of P6 TF is not significant for projects with 30 activities. P6 TF has not better solutions than MS-Standart for projects with 30 activities.

Analysis with t-test results for 60 activities are given in table 3-27. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is rejected since t stat (1.38) is smaller than t critical (1.76).

Table 3-27: t-test: Paired Two Sample for Means Analysis for Best Results of P6 TF & MS Standart for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS Standart</b>	<b>P6 TF</b>
<b>Mean</b>	96,66666667	95
<b>Variance</b>	930,5238095	749,2857143
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1,377696528</b>	
<b>t Critical one-tail</b>	1,761310115	

The result of the t-test indicate that the difference between mean values of MS-Standard and best results of P6 TF is not significant for projects with 60 activities. P6 TF has not better solutions than MS-Standard for projects with 60 activities.

Analysis with t-test results for 120 activities are given in table 3-28. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.11) is larger than t critical (1.76).

The result of the t-test indicate that the difference between mean values of MS-Standard and best results of P6 TF is significant for projects with 120 activities. P6 TF has better solutions than MS-Standard for projects with 120 activities.

Table 3-28: t-test: Paired Two Sample for Means Analysis for Best Results of P6 TF & MS Standard for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS Standard</b>	<b>P6 TF</b>
<b>Mean</b>	163,2666667	149,6666667
<b>Variance</b>	4675,638095	2824,952381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>2,107191946</b>	
<b>t Critical one-tail</b>	1,761310115	

The values are successively shown below for test statistic > critical value;

**30 Activities** → 0,748026223 < 1,76131

**60 Activities** → 1,377696528 < 1,76131

**120 Activities** → 2,107191946 > 1,76131

There is a significant difference between Best Results of P6 TF and MS-Standard for only 120 activities for resource allocation capability for resource constrained project scheduling problems. In conclusion, P6 TF has better solutions than MS-Standard for projects with 120 activities.

It is considered that there is a significant difference between mean values of MS-Standard and best results of P6 LFT. Details are given for projects with 30, 60 and 120 activities in table A-41 to A-43 in appendix part successively. To verify this claim the following t-test was used.

Analysis with t-test results for 30 activities are given in table 3-29. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is accepted and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is rejected since t stat (1.18) is smaller than t critical (1.76). The result of the t-test indicate that the difference between mean values of MS-Standard and best results of P6 LFT is not significant for projects with 30 activities. P6 LFT has not better solutions than MS-Standard for projects with 30 activities.

Table 3-29: t-test: Paired Two Sample for Means Analysis for Best Results of P6 LFT & MS Standard for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS Standard</b>	<b>P6 LFT</b>
<b>Mean</b>	61,53333	62,93333
<b>Variance</b>	197,8381	195,781
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>1,18808</b>	
<b>t Critical one-tail</b>	1,76131	

Analysis with t-test results for 60 activities are given in table 3-30. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (2.02) is larger

than t critical (1.76). The result of the t-test indicate that the difference between mean values of MS-Standart and best results of P6 LFT is significant for projects with 60 activities. P6 LFT has better solutions than MS-Standart for projects with 60 activities.

Table 3-30: t-test: Paired Two Sample for Means Analysis for Best Results of P6 LFT & MS Standart for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>MS Standart</b>	<b>P6 LFT</b>
<b>Mean</b>	96,66667	93,53333
<b>Variance</b>	930,5238	724,4095
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>2,023093</b>	
<b>t Critical one-tail</b>	1,76131	

Analysis with t-test results for 120 activities are given in table 3-31. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is accepted since t stat (2.74) is larger than t critical (1.76). The result of the t-test indicate that the difference between mean values of MS-Standart and best results of P6 LFT is significant for projects with 120 activities. P6 LFT has better solutions than MS-Standart for projects with 120 activities.

Table 3-31: t-test: Paired Two Sample for Means Analysis for Best Results of P6 LFT & MS Standart for 120 Activities

t-test: Paired Two Sample for Means	MS Standart	P6 LFT
Mean	163,2667	143,8667
Variance	4675,638	2446,124
Observations	15	15
Hypothesized Mean Difference	0	
df	14	
t Stat	<b>2,742321</b>	
t Critical one-tail	1,76131	

The values are successively shown below for test statistic > critical value;

**30 Activities** → 1,18808 < 1,76131

**60 Activities** → 2,023093 > 1,76131

**120 Activities** → 2,742321 > 1,76131

There is a significant difference between Best Results of P6 LFT and MS Standart for 60 and 120 activities. In conclusion, it will be sufficient to examine P6 LFT priority with 2 consecutive iterations for P6 users for projects with 60 and 120 activities for resource allocation capability for resource constrained projects.

### 3.3 Deviation of P6 & MS Project 2007 Results from Benchmarks

Kolisch and Hartmann (2006) defined benchmarks as, the optimal solution for the J30 set, the well-known critical path-based lower bound is for J60 and J120 sets since some of the optimal solutions are unknown for J60 and J120 sets.

Third comparison is between the best results of MS and P6 with the optimum and lower bound solutions. Details are given in tables A-26 to A-28 in appendix part. T-

test analysis are shown in tables 3-32 to 3-34 for 30, 60 and 120 activities successively. % deviation of best results' of P6 and MS from benchmark is 0-12 % for 30 activities. Details are given in table A-44 in appendix part.

Analysis with t-test results for 30 activities are given in table 3-32. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is accepted since t stat (3.38) is larger than t critical (1.76). The result of the t-test indicate that results of optimum solutions are better than the best results of MS and P6 for the RCPSP for projects with 30 activities. % deviation of best results' of P6 and MS from benchmark is 0-29 % for 60 activities. Details are given in table A-45 in appendix part.

Table 3-32: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & MS with Optimum Solutions for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>Best of MS &amp; P6</b>	<b>Optimum</b>
<b>Mean</b>	59,86666667	57,46666667
<b>Variance</b>	169,9809524	131,6952381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>3,384456449</b>	
<b>t Critical one-tail</b>	1,761310115	

Analysis with t-test results for 60 activities are given in table 3-33. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is accepted since t stat (3.22) is larger than t critical (1.76). The result of the t-test indicate that results of lower bound solutions are better than the best results of MS and P6 for the RCPSP for projects with 60 activities.

Table 3-33: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & MS with Lower Bound Solutions for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>Best of MS &amp; P6</b>	<b>Optimum</b>
<b>Mean</b>	92,53333333	81,93333333
<b>Variance</b>	719,552381	243,4952381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>3,218672471</b>	
<b>t Critical one-tail</b>	1,761310115	

% deviation of best results' of P6 and MS from benchmark is 0-31 % for 120 activities. Details are given in table A-46 in appendix part. Analysis with t-test results for 120 activities are given in table 3-34. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0$  ( $\mu_1 > \mu_2$ ) is accepted since t stat (4.98) is larger than t critical (1.76). The result of the t-test indicate that results of lower bound solutions are better than the best results of MS and P6 for the RCPSP for projects with 120 activities.

Table 3-34: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & MS with Lower Bound Solutions for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>Best of MS &amp; P6</b>	<b>Optimum</b>
<b>Mean</b>	143,2	120,4666667
<b>Variance</b>	2471,314286	1117,409524
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>4,977249884</b>	
<b>t Critical one-tail</b>	1,761310115	

The values are successively shown below for test statistic > critical value;

**30 Activities** → 3,384456449 > 1,76131

**60 Activities** → 3,218672471 > 1,76131

**120 Activities** → 4,977249884 > 1,76131

There is a significant difference between Best Results of P6 and MS between optimum solutions for 30, 60 and 120 activities. In conclusion, new algorithms should be implemented into project management software packages to get optimum or near optimum results.

### **3.4 Comparison of Best Results of P6 and MS with Best Results of Heuristic Solution Results Using t-test**

Kolisch and Hartmann (2006) stated lower and upper bound definition as follows; “Möhring et al. (2003) proposed a Lagrange heuristic. The method first generates an upper bound of the project makespan by employing a multi-priority rule method. Afterwards, a Lagrange relaxation (LR) and a list scheduling heuristic are invoked iteratively, in order to generate lower and upper bounds for the RCPSP. The Lagrange relaxation of the RCPSP is solved in polynomial time and the precedence feasible start times are employed as input for a list scheduling procedure. The latter generates a number of different precedence and resource feasible schedules by scheduling the activities in non-increasing order of their start time plus the processing times multiplied by a constant.”

Fourth comparison is between the best results of MS and P6 with the best of heuristic solutions. Details are given in tables A-29 to A-31 in appendix part. T-test analysis are shown in tables 3-35 to 3-37 for 30, 60 and 120 activities successively.

% deviation of best results' of P6 and MS from upper bound is 0-12 % for 30 activities. Details are given in table A-47 in appendix part.

Analysis with t-test results for 30 activities are given in table 3-35. The null hypothesis for 30 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is accepted since t stat (3.38) is larger than t critical (1.76). The result of the t-test indicate that best results of heuristic solutions, upper bounds, are better than the best results of MS and P6 for the RCPSP for projects with 30 activities.

Table 3-35: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & MS with Heuristic Solutions for 30 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>Best of MS &amp; P6</b>	<b>Heuristic</b>
<b>Mean</b>	59,86666667	57,46666667
<b>Variance</b>	169,9809524	131,6952381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>3,384456449</b>	
<b>t Critical one-tail</b>	1,761310115	

% deviation of best results' of P6 and MS from upper bound is 0-20 % for 60 activities. Details are given in table A-48 in appendix part.

Analysis with t-test results for 60 activities are given in table 3-36. The null hypothesis for 60 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is accepted since t stat (3.35) is larger than t critical (1.76). The result of the t-test indicate that best results of heuristic solutions, upper bounds, are better than the best results of MS and P6 for the RCPSP for projects with 60 activities.

Table 3-36: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & MS with Heuristic Solutions for 60 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>Best of MS &amp; P6</b>	<b>Heuristic</b>
<b>Mean</b>	92,53333333	85,66666667
<b>Variance</b>	719,552381	405,3809524
<b>Observations</b>	15	15
<b>Pearson Correlation</b>	0,98326502	
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>3,354903936</b>	
<b>t Critical one-tail</b>	1,761310115	

% deviation of best results' of P6 and MS from upper bound is 0-27 % for 120 activities. Details are given in table A-49 in appendix part.

Analysis with t-test results for 120 activities are given in table 3-37. The null hypothesis for 120 activities is  $H_0: d = \mu_1 - \mu_2 = 0$ . The null hypothesis is rejected and alternative hypothesis  $H_1: d > 0 (\mu_1 > \mu_2)$  is accepted since t stat (4.65) is larger than t critical (1.76).

Table 3-37: t-test: Paired Two Sample for Means Analysis for Best Results of P6 & MS with Heuristic Solutions for 120 Activities

<b>t-test: Paired Two Sample for Means</b>	<b>Best of MS &amp; P6</b>	<b>Heuristic</b>
<b>Mean</b>	143,2	127,0666667
<b>Variance</b>	2471,314286	1466,92381
<b>Observations</b>	15	15
<b>Hypothesized Mean Difference</b>	0	
<b>df</b>	14	
<b>t Stat</b>	<b>4,646487514</b>	
<b>t Critical one-tail</b>	1,761310115	

The result of the t-test indicate that best results of heuristic solutions, upper bounds, are better than the best results of MS and P6 for the RCPSP for projects with 120 activities.

The values are successively shown below for test statistic > critical value;

**30 Activities** → 3,384456449 > 1,76131

**60 Activities** → 3,354903936 > 1,76131

**120 Activities** → 4,646487514 > 1,76131

There is a significant difference between Best Results of P6 and MS between best results of heuristic solutions, upper bounds for 30, 60 and 120 activities. In conclusion, new algorithms should be implemented into project management software packages to get optimum or near optimum results.

### 3.5 General Evaluation

The summary of t-test analysis for the ten comparisons, as mentioned in section 3.2, are given below;

1. t-test analysis of best results of P6 between best results of MS are shown in table 3-38;

P6 has better results than MS for projects with 30, 60 and 120 activities. Among the methods tested for Primavera V.6.0 P6 Default, P6 LFT with 2 consecutive iterations and P6 TF with 10 consecutive iterations are better choices for resource allocation for most of the projects.

Table 3-38: t-test Results for Best Results of P6 & Best Results of MS with Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 &amp; BEST RESULTS OF MS PROJECT 2007</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
P6 has better results than MS Project 2007	J=30	Significant
P6 has better results than MS Project 2007	J=60	Significant
P6 has better results than MS Project 2007	J=120	Significant

2. t-test analysis of MS-Standart between MS-ID are shown in table 3-39;

MS-Standart has better results than MS-ID for projects with 30, 60 and 120 activities. When MS Project 2007 is used for resource allocation, MS-Standart is a better choice for resource allocation for most of the projects.

Table 3-39: t-test Results for MS-Standart & MS-ID Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>MS PROJECT 2007 STANDART &amp; MS PROJECT 2007 ID</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
MS Standart has better results than ID	J=30	Significant
MS Standart has better results than ID	J=60	Significant
MS Standart has better results than ID	J=120	Significant

3. t-test analysis of P6-TF between P6-Default are shown in table 3-40;

P6-TF has better results than P6-Default for projects with 30, 60 and 120 activities. When P6 is used for resource allocation, P6-TF will be better choice than P6-Default for resource allocation for most of the projects.

Table 3-40: t-test Results for Best Results of P6-TF & P6-Default Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 TF &amp; P6 DEFAULT</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
P6 TF has better results than P6 Default	J=30	Significant
P6 TF has better results than P6 Default	J=60	Significant
P6 TF has better results than P6 Default	J=120	Significant

4. t-test analysis of P6-LFT between P6-Default are shown in table 3-41;

P6-LFT has better results than P6-Default for projects with 30, 60 and 120 activities. When P6 is used for resource allocation, P6-LFT will be better choice than P6-Default for resource allocation for most of the projects. Over 85 % P6-LFT gives the best results for the forty-five randomly selected projects.

Table 3-41: t-test Results for Best Results of P6-LFT & P6-Default Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 LFT &amp; P6 DEFAULT</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
P6 LFT has better results than P6 Default	J=30	Significant
P6 LFT has better results than P6 Default	J=60	Significant
P6 LFT has better results than P6 Default	J=120	Significant

5. t-test analysis of P6-LFT between P6-TF are shown in table 3-42;

There is no significant difference between mean values of P6-LFT and P6-TF for projects with 30 activities. P6-LFT has better results than P6-TF for projects with 60 and 120 activities. When P6 is used for resource allocation, P6-LFT will be better choice than P6-TF for resource allocation for most of the projects.

Table 3-42: t-test Results for Best Results of P6-LFT & Best Results of P6-TF Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 TF &amp; BEST RESULTS OF P6 LFT</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
P6 TF has better results than P6 LFT	J=30	Insignificant
P6 LFT has better results than P6 TF	J=60	Significant
P6 LFT has better results than P6 TF	J=120	Significant

6. t-test analysis of best results of MS between MS Standart are shown in table 3-43;

Verified solution is that the mean difference between MS Standart and best results of MS are not significant for J=30,60,120. Two samples are not different for J=30,60,120. It will be sound choice examining only MS-Standart to obtain best results for MS users.

Table 3-43: t-test Results for Best Results of MS & MS Standart Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF MS &amp; MS STANDART</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of MS has better results than MS Standart	J=30	Insignificant
Best Result of MS has better results than MS Standart	J=60	Insignificant
Best Result of MS has better results than MS Standart	J=120	Insignificant

7. t-test analysis of best results of P6 between best results of P6 LFT are shown in table 3-44;

There is a significant difference between Best Results of P6 LFT and Best Results of P6 for 30 activities. In conclusion, P6 Default and P6 TF should be investigated for better results for 30 activities.

There is not a significant difference between Best Results of P6 LFT and Best Results of P6 for projects with 60,120 activities for resource allocation capability for resource constrained project scheduling problems. In conclusion, it will be sufficient to examine P6 LFT priority with consecutive 2 iterations for P6 users for for projects with 60,120 activities for resource allocation capability for resource constrained projects.

Table 3-44: t-test Results for Best Results of P6 & Best Results of P6-LFT Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 &amp; BEST RESULTS OF P6 LFT</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of P6 has better results than P6 LFT	J=30	Significant
Best Result of P6 has better results than P6 LFT	J=60	Insignificant
Best Result of P6 has better results than P6 LFT	J=120	Insignificant

8. t-test analysis of best results of P6 between best results of P6 TF are shown in table 3-45;

There is a significant difference between Best Results of P6 TF and Best Results of P6 for 30, 60 and 120 activities for resource allocation capability for resource constrained project scheduling problems. In conclusion, it should be investigated with P6 Default and P6 LFT priority with consecutive 2 iterations for P6 users for better results for 30 activities.

Table 3-45: t-test Results for Best Results of P6 & Best Results of P6-TF Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 &amp; BEST RESULTS OF P6 TF</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of P6 has better results than P6 TF	J=30	Insignificant
Best Result of P6 has better results than P6 TF	J=60	Significant
Best Result of P6 has better results than P6 TF	J=120	Significant

9. t-test analysis of best results of P6 TF between MS-Standard are shown in table 3-46;

There is a significant difference between Best Results of P6 TF and MS-Standard for only 120 activities for resource allocation capability for resource constrained project scheduling problems. In conclusion, P6 TF has better solutions than MS-Standard for projects with 120 activities.

Table 3-46: t-test Results for Best Results of P6-TF & MS-Standart Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 TF &amp; MS STANDART</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of P6 TF has better results than MS	J=30	Insignificant
Best Result of P6 TF has better results than MS	J=60	Insignificant
Best Result of P6 TF has better results than MS	J=120	Insignificant

10. t-test analysis of best results of P6 LFT between MS-Standart are shown in table 3-47;

There is a significant difference between Best Results of P6 LFT and MS Standart for 60 and 120 activities. In conclusion, it will be sufficient to examine P6 LFT priority with 2 consecutive iterations for P6 users for projects with 60 and 120 activities for resource allocation capability for resource constrained projects.

Table 3-47: t-test Results for Best Results of P6-LFT & MS-Standart Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 LFT &amp; MS STANDART</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of P6 LFT has better results than MS Standart	J=30	Insignificant
Best Result of P6 LFT has better results than MS Standart	J=60	Insignificant
Best Result of P6 LFT has better results than MS Standart	J=120	Significant

P6 analysis are summarized in table 3-48. P6 TF has better results for projects with smaller activities and P6 LFT has better results for projects with larger activities to get closer with best results of P6 for RCPSP.

Table 3-48: t-test Results for Best Results of P6 Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 &amp; P6 LFT</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of P6 has better results than P6 LFT	J=30	Significant
Best Result of P6 has better results than P6 LFT	J=60	Insignificant
Best Result of P6 has better results than P6 LFT	J=120	Insignificant
<b>BEST RESULTS OF P6 &amp; P6 TF</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of P6 has better results than P6 TF	J=30	Insignificant
Best Result of P6 has better results than P6 TF	J=60	Significant
Best Result of P6 has better results than P6 TF	J=120	Significant

MS analysis are summarized in table 3-49. MS Standart has better results for projects with smaller and larger activities to get closer with best results of MS for RCPSP.

Table 3-49: t-test Results for Best Results of MS Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF MS &amp; MS STANDART</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of MS has better results than MS Standart	J=30	Insignificant
Best Result of MS has better results than MS Standart	J=60	Insignificant
Best Result of MS has better results than MS Standart	J=120	Insignificant

MS and P6 analysis are summarized in table 3-50. P6 has usually better results for projects with smaller and larger activities to get closer with best results as resource allocation capabilities of P6 and MS for RCPSP. P6 LFT has better results than MS Standart for projects with larger activities for RCPSP.

Table 3-50: t-test Results for Best Results of P6 & MS Leveling Priorities

<b>RESOURCE ALLOCATION CAPABILITIES OF SOFTWARE PACKAGES</b>		
<b>BEST RESULTS OF P6 &amp; MS PROJECT 2007</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
P6 has better results than MS Project 2007	J=30	Significant
P6 has better results than MS Project 2007	J=60	Significant
P6 has better results than MS Project 2007	J=120	Significant
<b>BEST RESULTS OF P6 LFT &amp; MS STANDART</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of P6 LFT has better results than MS Standart	J=30	Insignificant
Best Result of P6 LFT has better results than MS Standart	J=60	Insignificant
Best Result of P6 LFT has better results than MS Standart	J=120	Significant
<b>BEST RESULTS OF P6 TF &amp; MS STANDART</b>		
<b>Claim Hypothesis</b>	<b>Data Sets</b>	<b>Paired t-test Results Of Difference</b>
Best Result of P6 TF has better results than MS Standart	J=30	Insignificant
Best Result of P6 TF has better results than MS Standart	J=60	Insignificant
Best Result of P6 TF has better results than MS Standart	J=120	Insignificant

## CHAPTER 4

### CONCLUSIONS

MS Project 2007 (MS) with its two priority rules ID and Standart and Primavera Enterprise V.6.0-Project Management (P6) with its three priority rules Default, minimum total float (TF) by 10 consecutive iterations and latest finish time (LFT) by 2 consecutive iterations are used for solving 45 resource overallocated instances generated from ProGen in RCPSP. The results are examined as the percentage deviation from optimum, lower bound and best results of heuristic solutions.

The results are analyzed with t-test: paired two sample for means to see the significance for the difference of the means of two sample. The results for the entire population analyzing 45 instances generated by ProGen are shown below;

- P6 shows better performance than MS for the forty-five randomly selected projects, for projects with 30, 60 and 120 activities with a success over 80 %. P6 even gives better results than MS for projects with larger activities near 85 % success.
- Both P6-LFT and P6-TF levelling priorities are above abroad against P6-Default over 85 %. It is advised for P6 users to select P6-TF leveling for smaller activities. However it is beneficial to check the P6-LFT leveling since there is not any significant best solution in P6 leveling priorities for projects with smaller activities. When P6 is used for resource allocation, P6-LFT will be better choice than P6-TF for resource allocation since P6 LFT is the best solution in P6 leveling priorities for projects with 60 and 120 activities. Over 83 % P6-LFT gives the best results for the thirty randomly selected projects for projects with 60 and 120 activities.

- It is advised for MS users to select MS-Standard leveling priority since over 75 % MS-Standard shows better performance than MS-ID for the forty-five randomly selected projects. MS-Standard is the best solution in MS leveling priorities for projects with 30, 60 and 120 activities.
- P6-TF with consecutive 10 iterations has better result probability than P6-LFT with consecutive 2 iterations to get closer with the best results for 30 activities
- P6-LFT with consecutive 2 iterations has better result probability than P6-TF with consecutive 10 iterations to get closer with the best results for 60 and 120 activities.

Last research conducted by Hekimoğlu (2007) indicated the results below;

- MS Project 2003 should be preferred to Primavera V.4.1-LFT for small problems, 30 activities.
- Primavera V.4.1-LFT should be used in order to obtain better results for the larger size problems for RCPSP's.
- Primavera V.4.1-TF method is not the proper choice for RCPSP's.

If the results are compared with Hekimoğlu (2007), one of the above results was different, there is not a significant difference for the means of MS Project 2007 and Primavera V.6.0-TF with 10 consecutive iterations for small problems in RCPSP. Since Primavera V.6.0-TF with 10 consecutive iterations gives its best results with successive iterations, it is worth to examine successive iterations. In conclusion, results indicated that it will be beneficial for P6 users to make necessary iterations for the corresponding leveling priorities.

Both MS and P6 gives its users the chance to determine the activity based leveling priority. An experienced project manager could achieve better results by assigning the appropriate activity based leveling priorities in the nature of the project environment with MS and P6.

Deviation for best results of MS and P6 from best results of heuristic solutions

1. % deviation of best results' of P6 and MS from upper bound or optimum is 0-12 % for 30 activities
2. % deviation of best results' of P6 and MS from upper bound is 0-20 % for 60 activities
3. % deviation of best results' of P6 and MS from upper bound is 0-27 % for 120 activities

There is a significant difference between best results of P6 and MS between best results of heuristic solutions, for 30, 60 and 120 activities. If the deviation from best results of heuristic solutions is nearly 30 % for 120 activities it will probably be much larger for larger projects that have more than 120 activities. In conclusion, the existing commonly used project management software is not sufficient for solving RCPSP. Heuristic algorithms may provide an alternative for improving the capabilities of existing project management software for RCPSP. New algorithms should be implemented into project management software packages to achieve optimum or near optimum results for RCPSP.

In this study, we examined 45 projects for 30, 60 and 120 activities which were generated by ProGen. Larger samples or other instances generated by different problem generators can be examined. Successive iterations used for P6 leveling priorities contributed to obtain better results. It is worth to make successive iterations corresponding to different leveling priority rules for P6 users.

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# APPENDIX

## TABLES

Table A- 1: P6 Default Leveling Priority with Consecutive 10 Iterations for 30 Activities

30 Activities											
ID	Project Nr	Minimum	P6 Default								
	Duration	1	2	3	4	5	6	7	8	9	10
1	187	57	57	57	57	57	57	57	57	57	57
2	125	82	82	82	82	82	82	82	82	82	82
3	455	63	63	63	63	63	63	63	63	63	63
4	139	58	58	58	58	58	58	58	58	58	58
5	201	97	97	97	97	97	97	97	97	97	97
6	328	82	82	82	82	82	82	82	82	82	82
7	209	95	95	95	95	95	95	95	95	95	95
8	175	56	56	56	56	56	56	56	56	56	56
9	461	62	62	62	62	62	62	62	62	62	62

Table A- 2: P6 TF Leveling Priority with Consecutive 10 Iterations for 30 Activities

30 Activities											
ID	Project Nr	Minimum	P6 Total Float								
	Duration	1	2	3	4	5	6	7	8	9	10
1	187	57	58	68	57	57	57	57	57	57	57
2	125	75	79	75	83	85	84	80	94	89	85
3	455	64	64	74	66	76	67	72	66	76	67
4	139	51	51	56	57	58	55	52	51	52	52
5	201	90	103	93	98	97	91	90	95	94	94
6	328	61	74	61	71	71	64	64	71	73	71
7	209	75	83	80	76	84	79	75	76	87	83
8	175	56	56	57	57	57	57	57	57	57	57
9	461	59	62	64	59	64	59	64	59	64	59

Table A- 3: P6 LFT Leveling Priority with Consecutive 10 Iterations for 30 Activities

30 Activities												
ID	Project Nr	Minimum	P6 LFT									
	Duration	1	2	3	4	5	6	7	8	9	10	
1	187	58	58	58	58	58	58	58	58	58	58	58
2	125	78	81	78	78	78	78	78	78	78	78	78
3	455	63	63	63	63	63	63	63	63	63	63	63
4	139	49	49	50	50	50	50	50	50	50	50	50
5	201	90	90	90	90	90	90	90	90	90	90	90
6	328	70	70	70	70	70	70	70	70	70	70	70
7	209	80	88	80	80	80	80	80	80	80	80	80
8	175	52	52	57	57	57	57	57	57	57	57	57
9	461	59	59	59	59	59	59	59	59	59	59	59

Table A- 4: P6 LFT After Applying P6 Default Leveling Priority with Consecutive 10 Iterations for 30 Activities

30 Activities												
ID	Project Nr	Minimum	P6 LFT After P6 Default									
	Duration	1	2	3	4	5	6	7	8	9	10	
1	187	57	57	57	57	57	57	57	57	57	57	57
2	125	77	77	77	77	77	77	77	77	77	77	77
3	455	62	62	62	62	62	62	62	62	62	62	62
4	139	54	54	54	54	54	54	54	54	54	54	54
5	201	91	91	91	91	91	91	91	91	91	91	91
6	328	77	77	77	77	77	77	77	77	77	77	77
7	209	75	75	75	75	75	75	75	75	75	75	75
8	175	56	56	56	56	56	56	56	56	56	56	56
9	461	59	59	59	59	59	59	59	59	59	59	59

Table A- 5: P6 TF After Applying P6 Default Leveling Priority with Consecutive 10 Iterations for 30 Activities

		30 Activities										
ID	Project Nr	Minimum	P6 TF After P6 Default									
	Duration	1	2	3	4	5	6	7	8	9	10	
1	187	57	57	57	57	57	57	57	57	57	57	
2	125	79	79	79	87	82	84	86	93	92	85	
3	455	65	65	65	68	72	67	72	66	76	67	
4	139	51	51	56	57	58	55	52	51	52	52	
5	201	95	97	95	95	95	95	95	95	95	95	
6	328	64	76	71	65	71	64	64	71	73	71	
7	209	76	79	85	76	78	82	84	89	80	76	
8	175	56	56	57	57	57	57	57	57	57	57	
9	461	62	62	62	62	62	62	62	62	62	62	

Table A- 6: P6 TF After Applying P6 LFT Leveling Priority with Consecutive 10 Iterations for 30 Activities

		30 Activities										
ID	Project Nr	Minimum	P6 TF After P6 LFT									
	Duration	1	2	3	4	5	6	7	8	9	10	
1	187	57	68	57	57	57	57	57	57	57	57	
2	125	78	82	85	78	87	88	84	80	91	81	
3	455	65	72	66	65	66	65	66	65	66	65	
4	139	52	53	53	59	59	55	60	52	57	53	
5	201	91	98	93	95	97	91	93	94	93	94	
6	328	61	61	77	73	71	73	71	73	71	73	
7	209	76	79	83	76	76	80	94	84	79	85	
8	175	57	57	57	57	57	57	57	57	57	57	
9	461	59	64	59	64	59	64	59	64	59	64	

Table A- 7: MS Project 2007 Leveling Priority Comparision for 30 Activities

<b>Project Duration ( Days )</b>				
<b>ID</b>	<b>Random Selection</b>	<b>MS Project 2007</b>	<b>MS Project 2007</b>	<b>MS Project 2007</b>
	<b>Project Nr</b>	<b>ID</b>	<b>Priority / Standart</b>	<b>Standart</b>
1	187	57	57	57
2	125	81	78	78
3	455	63	62	62
4	139	61	52	52
5	201	95	96	96
6	328	79	63	63
7	209	89	74	74
8	175	56	52	52
9	461	62	58	58

Table A- 8: Best Results of MS Project 2007 and P6 with Corresponding Leveling Priority for 30 Activities

<b>30 Activities</b>		<b>Project Duration ( Days )</b>			
<b>ID</b>	<b>Random Selection</b>	<b>CPM</b>	<b>Min MS-P6</b>	<b>Allocation</b>	<b>Iteration #</b>
	<b>Project Nr</b>	<b>Days</b>	<b>Duration</b>	<b>P6-MS</b>	<b>P6</b>
1	187	54	57	P6 Default	1
2	125	43	75	P6 Total Float	2
3	455	56	62	MS PROJECT 2007	Standart
4	139	44	49	P6 LFT	1
5	201	60	90	P6 LFT	1
6	328	47	61	P6 Total Float	2
7	209	43	74	MS PROJECT 2007	Standart
8	175	50	52	P6 LFT	1
9	461	58	58	MS PROJECT 2007	Standart
10	185	47	48	P6 LFT- Total Float	1
11	166	63	63	P6 LFT-Total Float	1
12	208	48	67	P6 Default	1
13	136	34	37	P6 Default	1
14	188	55	55	P6 Total Float	1
15	6	39	50	P6 Total Float	6

Table A- 9: Best Results of MS Project 2007 and P6 with Corresponding Leveling  
Priority for 60 Activities

60 Activities		Project Duration ( Days )			
Id	Random Selection	CPM	Min Ms-P6	Allocation	Iteration #
	Project Nr	Days	Duration	P6-MS	P6
1	376	86	86	P6 Late Finish	2
2	10	76	81	MS Project 2007	Standart
3	3	67	71	MS Project 2007	Standart
4	249	69	114	P6 Late Finish	1
5	387	68	68	P6 Late Finish	1
6	127	54	103	P6 Total Float	10
7	445	60	123	P6 Late Finish	2
8	2	65	70	P6 Late Finish	1
9	406	82	151	P6 Total Float	7
10	58	72	72	MS Project 2007	Standart
				P6-LFT-TF	1
11	123	57	105	P6 Late Finish	2
12	19	65	65	P6 Late Finish	1
13	224	83	83	MS Project 2007	Standart
				P6 Total Float	1
14	184	67	67	MS Project 2007	Standart
				P6 Total Float	1
15	450	61	129	P6 Late Finish	2

Table A-10: Best Results of MS Project 2007 and P6 with Corresponding Leveling  
Priority for 120 Activities

120 Activities		Project Duration ( Days )			
ID	Random Selection	CPM	Min MS-P6	Allocation	Iteration #
	Project Nr	Days	Duration	P6-MS	P6
1	31	70	78	P6 Total Float	1
2	114	92	149	P6 Late Finish	1
3	209	86	115	P6 Total Float	5
4	104	90	222	P6 Late Finish	1
5	316	94	148	P6 Late Finish	2

Table A-10: Best Results of MS Project 2007 and P6 with Corresponding Leveling Priority for 120 Activities (Continued)

120 Activities		Project Duration ( Days )			
ID	Random Selection	CPM	Min MS-P6	Allocation	Iteration #
	Project Nr	Days	Duration	P6-MS	P6
6	478	103	128	P6 Late Finish	2
7	157	90	218	P6 Late Finish	2
8	433	107	107	P6 Total Float	1
9	472	88	129	P6 Late Finish	2
10	406	90	118	MS Project 2007	Standart
11	67	93	133	P6 Late Finish	2
12	479	108	143	MS Project 2007	Standart
13	227	104	104	P6 Late Finish	1
14	216	93	103	P6 Late Finish	2
15	357	110	253	P6 Late Finish	2

Table A-11: Best Results of MS & P6 for 30 Activities

30 Activities		Project Duration ( Days )	
ID	Random Selection	Min MS	Min P6
	Project Nr	Duration	Duration
1	187	57	57
2	125	78	75
3	455	62	62
4	139	52	49
5	201	95	90
6	328	63	61
7	209	74	75
8	175	52	52
9	461	58	59
10	185	50	48
11	166	65	63
12	208	67	67
13	136	37	37
14	188	55	55
15	6	50	50

Table A-12: Best Results of MS & P6 for 60 Activities

60 Activities		Project Duration ( Days )	
ID	Random Selection	Min MS	Min P6
	Project Nr	Duration	Duration
1	376	92	86
2	10	81	84
3	3	71	76
4	249	120	114
5	387	69	68
6	127	105	103
7	445	136	123
8	2	72	70
9	406	157	151
10	58	72	72
11	123	107	105
12	19	71	65
13	224	83	83
14	184	67	67
15	450	143	129

Table A-13: Best Results of MS & P6 for 120 Activities

120 Activities		Project Duration ( Days )	
ID	Random Selection	Min MS	Min P6
	Project Nr	Duration	Duration
1	31	80	78
2	114	164	149
3	209	129	115
4	104	335	222
5	316	168	148
6	478	137	128
7	157	240	218
8	433	113	107
9	472	135	129
10	406	118	120
11	67	148	133

Table A-13: Best Results of MS & P6 for 120 Activities (Continued)

120 Activities		Project Duration ( Days )	
ID	Random Selection	Min MS	Min P6
	Project Nr	Duration	Duration
12	479	143	146
13	227	117	104
14	216	128	103
15	357	277	253

Table A-14: Comparison of MS Project 2007 Leveling Priorities for 30 Activities

30 Activities		Project Duration ( Days )		
ID	Random Selection	Min MS	MS Project 2007	MS Project 2007
	Project Nr	Duration	ID	Standart
1	187	57	57	57
2	125	78	81	78
3	455	62	63	62
4	139	52	61	52
5	201	95	95	96
6	328	63	79	63
7	209	74	89	74
8	175	52	56	52
9	461	58	62	58
10	185	50	52	50
11	166	65	65	65
12	208	67	67	72
13	136	37	37	39
14	188	55	58	55
15	6	50	62	50

Table A-15: Comparison of MS Project 2007 Leveling Priorities for 60 Activities

60 Activities		Project Duration ( Days )		
ID	Random Selection	Min MS	MS Project 2007	MS Project 2007
	Project Nr	Duration	ID	Standart
1	376	92	106	92
2	10	81	84	81
3	3	71	90	71
4	249	120	136	120
5	387	69	72	69
6	127	105	114	105
7	445	136	136	139
8	2	72	85	72
9	406	157	170	157
10	58	72	84	72
11	123	107	112	107
12	19	71	71	71
13	224	83	92	83
14	184	67	67	67
15	450	143	143	144

Table A-16: Comparison of MS Project 2007 Leveling Priorities for 120 Activities

120 Activities		Project Duration ( Days )		
ID	Random Selection	Min MS	MS Project 2007	MS Project 2007
	Project Nr	Duration	ID	Standart
1	31	80	89	80
2	114	164	169	164
3	209	129	142	129
4	104	335	339	335
5	316	168	175	168
6	478	137	137	147
7	157	240	250	240
8	433	113	113	117
9	472	135	135	135
10	406	118	143	118

Table A-16: Comparison of MS Project 2007 Leveling Priorities for 120 Activities  
(Continued)

120 Activities		Project Duration ( Days )		
ID	Random Selection	Min MS	MS Project 2007	MS Project 2007
	Project Nr	Duration	ID	Standart
11	67	148	168	148
12	479	143	166	143
13	227	117	117	120
14	216	128	129	128
15	357	277	286	277

Table A-17: P6 Default & Best Results of P6 Total Float with 10 consecutive iteration for 30 Activities

30 Activities			
ID	Random Selection	Result	Best Result
	Project Nr	P6 Default	P6 Total Float
1	187	57	57
2	125	82	75
3	455	63	64
4	139	58	51
5	201	97	90
6	328	82	61
7	209	95	75
8	175	56	56
9	461	62	59
10	185	52	48
11	166	65	63
12	208	67	74
13	136	37	38
14	188	58	55
15	6	62	50

Table A-18: P6 Default & Best Results of P6 Total Float with 10 consecutive iteration for 60 Activities

<b>60 Activities</b>			
<b>ID</b>	<b>Random Selection</b>	<b>Result</b>	<b>Best Result</b>
	<b>Project Nr</b>	<b>P6 Default</b>	<b>P6 Total Float</b>
1	376	95	91
2	10	84	84
3	3	90	76
4	249	128	118
5	387	77	69
6	127	115	103
7	445	139	126
8	2	85	76
9	406	154	151
10	58	92	72
11	123	106	107
12	19	71	65
13	224	92	83
14	184	74	67
15	450	145	137

Table A-19: P6 Default & Best Results of P6 Total Float with 10 consecutive iteration for 120 Activities

<b>120 Activities</b>			
<b>ID</b>	<b>Random Selection</b>	<b>Result</b>	<b>Best Result</b>
	<b>Project Nr</b>	<b>P6 Default</b>	<b>P6 Total Float</b>
1	31	92	78
2	114	157	151
3	209	133	115
4	104	234	236
5	316	161	160
6	478	139	140
7	157	230	231
8	433	116	107
9	472	139	134

Table A-19: P6 Default & Best Results of P6 Total Float with 10 consecutive iteration for 120 Activities (Continued)

120 Activities			
ID	Random Selection	Result	Best Result
	Project Nr	P6 Default	P6 Total Float
10	406	133	126
11	67	153	146
12	479	157	149
13	227	118	104
14	216	121	107
15	357	260	261

Table A-20: P6 Default & Best Results of P6 LFT with 2 consecutive iterations for 30 Activities

30 Activities			
ID	Random Selection	Result	Best Result
	Project Nr	P6 Default	P6 LFT
1	187	57	58
2	125	82	78
3	455	63	63
4	139	58	49
5	201	97	90
6	328	82	70
7	209	95	80
8	175	56	52
9	461	62	59
10	185	52	48
11	166	65	63
12	208	67	78
13	136	37	39
14	188	58	55
15	6	62	62

Table A-21: P6 Default & Best Results of P6 LFT with 2 consecutive iterations for  
60 Activities

60 Activities			
ID	Random Selection	Result	Best Result
	Project Nr	P6 Default	P6 LFT
1	376	95	86
2	10	84	84
3	3	90	76
4	249	128	114
5	387	77	68
6	127	115	104
7	445	139	123
8	2	85	70
9	406	154	154
10	58	92	72
11	123	106	105
12	19	71	65
13	224	92	86
14	184	74	67
15	450	145	129

Table A-22: P6 Default & Best Results of P6 LFT with 2 consecutive iterations for  
120 Activities

120 Activities			
ID	Random Selection	Result	Best Result
	Project Nr	P6 Default	P6 LFT
1	31	92	78
2	114	157	149
3	209	133	120
4	104	234	222
5	316	161	148
6	478	139	128
7	157	230	218
8	433	116	107

Table A-22: P6 Default & Best Results of P6 LFT with 2 consecutive iterations for 120 Activities (Continued)

120 Activities			
ID	Random Selection	Result	Best Result
	Project Nr	P6 Default	P6 LFT
9	472	139	129
10	406	133	120
11	67	153	133
12	479	157	146
13	227	118	104
14	216	121	103
15	357	260	253

Table A-23: Best Results of P6 TF with 2 consecutive iterations & P6 TF with 10 consecutive iterations for 30 Activities

30 Activities			
ID	Random Selection	Best Result	Best Result
	Project Nr	P6 Total Float	P6 Late Finish
1	187	57	58
2	125	75	78
3	455	64	63
4	139	51	49
5	201	90	90
6	328	61	70
7	209	75	80
8	175	56	52
9	461	59	59
10	185	48	48
11	166	63	63
12	208	74	78
13	136	38	39
14	188	55	55
15	6	50	62

Table A-24: Best Results of P6 TF with 2 consecutive iterations & P6 TF with 10 consecutive iterations for 60 Activities

60 Activities			
ID	Random Selection	Best Result	Best Result
	Project Nr	P6 Total Float	P6 Late Finish
1	376	91	86
2	10	84	84
3	3	76	76
4	249	118	114
5	387	69	68
6	127	103	104
7	445	126	123
8	2	76	70
9	406	151	154
10	58	72	72
11	123	107	105
12	19	65	65
13	224	83	86
14	184	67	67
15	450	137	129

Table A-25: Best Results of P6 TF with 2 consecutive iterations & P6 TF with 10 consecutive iterations for 120 Activities

120 Activities			
ID	Random Selection	Best Result	Best Result
	Project Nr	P6 Total Float	P6 Late Finish
1	31	78	78
2	114	151	149
3	209	115	120
4	104	236	222
5	316	160	148
6	478	140	128
7	157	231	218
8	433	107	107

Table A-25: Best Results of P6 TF with 2 consecutive iterations & P6 TF with 10 consecutive iterations for 120 Activities (Continued)

120 Activities			
ID	Random Selection	Best Result	Best Result
	Project Nr	P6 Total Float	P6 Late Finish
9	472	134	129
10	406	126	120
11	67	146	133
12	479	149	146
13	227	104	104
14	216	107	103
15	357	261	253

Table A-26: Best Results of MS & P6 and Optimum Solutions for 30 Activities

30 Activities		Project Duration (Days)	
ID	Random Selection	Best Results	Optimum
	Project Nr	MS-P6	Results
1	187	57	57
2	125	75	67
3	455	62	57
4	139	49	46
5	201	90	84
6	328	61	61
7	209	74	69
8	175	52	52
9	461	58	58
10	185	48	48
11	166	63	63
12	208	67	62
13	136	37	35
14	188	55	55
15	6	50	48

Table A-27: Best Results of MS & P6 and Lower Bound Solutions for 60 Activities

60 Activities		Project Duration (Days)	
ID	Random Selection	Best Results	Lower Bound
	Project Nr	MS-P6	Results
1	376	86	86
2	10	81	80
3	3	71	68
4	249	114	89
5	387	68	68
6	127	103	80
7	445	123	99
8	2	70	68
9	406	151	120
10	58	72	72
11	123	105	82
12	19	65	65
13	224	83	83
14	184	67	67
15	450	129	102

Table A-28: Best Results of MS & P6 and Lower Bound Solutions for 120 Activities

120 Activities		Project Duration (Days)	
ID	Random Selection	Best Results	Lower Bound
	Project Nr	MS-P6	Results
1	31	78	74
2	114	149	121
3	209	115	97
4	104	222	175
5	316	148	120
6	478	128	108
7	157	218	174
8	433	107	107
9	472	129	110

Table A-28: Best Results of MS & P6 and Lower Bound Solutions for 120 Activities (Continued)

120 Activities		Project Duration (Days)	
ID	Random Selection	Best Results	Lower Bound
	Project Nr	MS-P6	Results
10	406	118	103
11	67	133	112
12	479	143	109
13	227	104	104
14	216	103	99
15	357	253	194

Table A-29: Best Results of MS & P6 and Best Results of Heuristic Solutions for 30 Activities

30 Activities		Project Duration (Days )	
ID	Random Selection	Best Results	Heuristic
	Project Nr	MS-P6	Results
1	187	57	57
2	125	75	67
3	455	62	57
4	139	49	46
5	201	90	84
6	328	61	61
7	209	74	69
8	175	52	52
9	461	58	58
10	185	48	48
11	166	63	63
12	208	67	62
13	136	37	35
14	188	55	55
15	6	50	48

Table A-30: Best Results of MS & P6 and Best Results of Heuristic Solutions for 60 Activities

60 Activities		Project Duration (Days )	
ID	Random Selection	Best Results	Heuristic
	Project Nr	MS-P6	Results
1	376	86	86
2	10	81	80
3	3	71	68
4	249	114	99
5	387	68	68
6	127	103	87
7	445	123	106
8	2	70	68
9	406	151	134
10	58	72	72
11	123	105	88
12	19	65	65
13	224	83	83
14	184	67	67
15	450	129	114

Table A-31: Best Results of MS & P6 and Best Results of Heuristic Solutions for 120 Activities

120 Activities		Project Duration (Days )	
ID	Random Selection	Best Results	Heuristic
	Project Nr	MS-P6	Results
1	31	78	74
2	114	149	125
3	209	115	102
4	104	222	196
5	316	148	128
6	478	128	116
7	157	218	186

Table A-31: Best Results of MS & P6 and Best Results of Heuristic Solutions for 120 Activities (Continued)

120 Activities		Project Duration (Days )	
ID	Random Selection	Best Results	Heuristic
	Project Nr	MS-P6	Results
8	433	107	107
9	472	129	113
10	406	118	113
11	67	133	118
12	479	143	113
13	227	104	104
14	216	103	103
15	357	253	208

Table A-32: Best Results of P6 LFT and Best Results of P6 for 30 Activities

30 Activities		Project Duration ( Days )	
Id	Project Nr	Best Results	Best Results
		P6 LFT	P6
1	187	58	57
2	125	78	75
3	455	63	63
4	139	49	49
5	201	90	90
6	328	70	61
7	209	80	75
8	175	52	52
9	461	59	59
10	185	48	48
11	166	63	63
12	208	78	67
13	136	39	37
14	188	55	55
15	6	62	50

Table A-33: Best Results of P6 LFT and Best Results of P6 for 60 Activities

60 Activities		Project Duration ( Days )	
ID	Project Nr	Best Results	Best Results
		P6 LFT	P6
1	376	86	86
2	10	84	84
3	3	76	76
4	249	114	114
5	387	68	68
6	127	104	103
7	445	123	123
8	2	70	70
9	406	154	151
10	58	72	72
11	123	105	105
12	19	65	65
13	224	86	83
14	184	67	67
15	450	129	129

Table A-34: Best Results of P6 LFT and Best Results of P6 for 120 Activities

120 Activities		Project Duration ( Days )	
ID	Project Nr	Best Results	Best Results
		P6 LFT	P6
1	31	78	78
2	114	149	149
3	209	120	115
4	104	222	222
5	316	148	148
6	478	128	128

Table A-34: Best Results of P6 LFT and Best Results of P6 for 120 Activities  
(Continued)

120 Activities		Project Duration ( Days )	
ID	Project Nr	Best Results	Best Results
		P6 LFT	P6
7	157	218	218
8	433	107	107
9	472	129	129
10	406	120	120
11	67	133	133
12	479	146	146
13	227	104	104
14	216	103	103
15	357	253	253

Table A-35: Best Results of P6 TF and Best Results of P6 for 30 Activities

30 Activities		Project Duration ( Days )	
ID	Project Nr	Best Results	Best Results
		P6 TF	P6
1	187	57	57
2	125	75	75
3	455	64	63
4	139	51	49
5	201	90	90
6	328	61	61
7	209	75	75
8	175	56	52
9	461	59	59
10	185	48	48
11	166	63	63
12	208	74	67
13	136	38	37
14	188	55	55
15	6	50	50

Table A-36: Best Results of P6 TF and Best Results of P6 for 60 Activities

60 Activities		Project Duration ( Days )	
ID	Project Nr	Best Results	Best Results
		P6 TF	P6
1	376	91	86
2	10	84	84
3	3	76	76
4	249	118	114
5	387	69	68
6	127	103	103
7	445	126	123
8	2	76	70
9	406	151	151
10	58	72	72
11	123	107	105
12	19	65	65
13	224	83	83
14	184	67	67
15	450	137	129

Table A-37: Best Results of P6 TF and Best Results of P6 for 120 Activities

120 Activities		Project Duration ( Days )	
ID	Project Nr	Best Results	Best Results
		P6 TF	P6
1	31	78	78
2	114	151	149
3	209	115	115
4	104	236	222
5	316	160	148
6	478	140	128
7	157	231	218
8	433	107	107
9	472	134	129
10	406	126	120
11	67	146	133
12	479	149	146
13	227	104	104

Table A-37: Best Results of P6 TF and Best Results of P6 for 120 Activities  
(Continued)

120 Activities		Project Duration ( Days )	
ID	Project Nr	Best Results	Best Results
		P6 TF	P6
14	216	107	103
15	357	261	253

Table A-38: Best Results of P6 TF & MS Standart for 30 Activities

30 Activities		Project Duration ( Days )	
ID	Project Nr	Results	Best Results
		MS Project 2007 Standart	P6 TF
1	187	57	57
2	125	78	75
3	455	62	64
4	139	52	51
5	201	96	90
6	328	63	61
7	209	74	75
8	175	52	56
9	461	58	59
10	185	50	48
11	166	65	63
12	208	72	74
13	136	39	38
14	188	55	55
15	6	50	50

Table A-39: Best Results of P6 TF & MS Standart for 60 Activities

60 Activities		Project Duration ( Days )	
ID	Project Nr	MS Project 2007	P6 Total Float
		Standart	Best Results
1	376	92	91
2	10	81	84

Table A-39: Best Results of P6 TF & MS Standart for 60 Activities (Continued)

60 Activities		Project Duration ( Days )	
ID	Project Nr	MS Project 2007	P6 Total Float
		Standart	Best Results
3	3	71	76
4	249	120	118
5	387	69	69
6	127	105	103
7	445	139	126
8	2	72	76
9	406	157	151
10	58	72	72
11	123	107	107
12	19	71	65
13	224	83	83
14	184	67	67
15	450	144	137

Table A-40: Best Results of P6 TF & MS Standart for 120 Activities

120 Activities		Project Duration ( Days )	
ID	Project Nr	MS Project 2007	P6 Total Float
		Standart	Best Results
1	31	80	78
2	114	164	151
3	209	129	115
4	104	335	236
5	316	168	160
6	478	147	140
7	157	240	231
8	433	117	107
9	472	135	134
10	406	118	126
11	67	148	146
12	479	143	149
13	227	120	104
14	216	128	107
15	357	277	261

Table A-41: Best Results of P6 LFT & MS Standart for 30 Activities

30 Activities		Project Duration ( Days )	
ID	Project Nr	Results	Best Results
		MS Project 2007 Standart	P6 LFT
1	187	57	58
2	125	78	78
3	455	62	63
4	139	52	49
5	201	96	90
6	328	63	70
7	209	74	80
8	175	52	52
9	461	58	59
10	185	50	48
11	166	65	63
12	208	72	78
13	136	39	39
14	188	55	55
15	6	50	62

Table A-42: Best Results of P6 LFT & MS Standart for 60 Activities

60 Activities		Project Duration ( Days )	
ID	Project Nr	Results	Best Results
		MS Project 2007 Standart	P6 LFT
1	376	92	86
2	10	81	84
3	3	71	76
4	249	120	114
5	387	69	68
6	127	105	104
7	445	139	123
8	2	72	70
9	406	157	154
10	58	72	72

Table A-42: Best Results of P6 LFT & MS Standart for 60 Activities (Continued)

60 Activities		Project Duration ( Days )	
ID	Project Nr	Results	Best Results
		MS Project 2007 Standart	P6 LFT
11	123	107	105
12	19	71	65
13	224	83	86
14	184	67	67
15	450	144	129

Table A-43: Best Results of P6 LFT & MS Standart for 120 Activities

120 Activities		Project Duration ( Days )	
ID	Project Nr	Results	Best Results
		MS Project 2007 Standart	P6 LFT
1	31	80	78
2	114	164	149
3	209	129	120
4	104	335	222
5	316	168	148
6	478	147	128
7	157	240	218
8	433	117	107
9	472	135	129
10	406	118	120
11	67	148	133
12	479	143	146
13	227	120	104
14	216	128	103
15	357	277	253

Table A-44: Comparison of Best Results of MS & P6 between Optimum Results  
for 30 Activities

30 Activities		Project Duration (Days)		
ID	Project Nr	Best Results	Results	Min MS-P6
		MS-P6	Optimum	% Deviation
1	187	57	57	0,00%
2	125	75	67	11,94%
3	455	62	57	8,77%
4	139	49	46	6,52%
5	201	90	84	7,14%
6	328	61	61	0,00%
7	209	74	69	7,25%
8	175	52	52	0,00%
9	461	58	58	0,00%
10	185	48	48	0,00%
11	166	63	63	0,00%
12	208	67	62	8,06%
13	136	37	35	5,71%
14	188	55	55	0,00%
15	6	50	48	4,17%

Table A-45: Comparison of Best Results of MS & P6 between Lower Bound Re-  
sults for 60 Activities

60 Activities		Project Duration (Days)		
ID	Project Nr	Min MS-P6	LB	Min MS-P6
		Duration		% Deviation
1	376	86	86	0,00%
2	10	81	80	1,25%
3	3	71	68	4,41%
4	249	114	89	28,09%
5	387	68	68	0,00%
6	127	103	80	28,75%
7	445	123	99	24,24%
8	2	70	68	2,94%
9	406	151	120	25,83%

Table A-45: Comparison of Best Results of MS & P6 between Lower Bound Results for 60 Activities (Continued)

60 Activities		Project Duration (Days)		
ID	Project Nr	Min MS-P6	LB	Min MS-P6
		Duration		% Deviation
10	58	72	72	0,00%
11	123	105	82	28,05%
12	19	65	65	0,00%
13	224	83	83	0,00%
14	184	67	67	0,00%
15	450	129	102	26,47%

Table A-46: Comparison of Best Results of MS & P6 between Lower Bound Results for 120 Activities

120 Activities		Project Duration (Days)		
ID	Project Nr	Min MS-P6	LB	Min MS-P6
		Duration		% Deviation
1	31	78	74	5,41%
2	114	149	121	23,14%
3	209	115	97	18,56%
4	104	222	175	26,86%
5	316	148	120	23,33%
6	478	128	108	18,52%
7	157	218	174	25,29%
8	433	107	107	0,00%
9	472	129	110	17,27%
10	406	118	103	14,56%
11	67	133	112	18,75%
12	479	143	109	31,19%
13	227	104	104	0,00%
14	216	103	99	4,04%
15	357	253	194	30,41%

Table A-47: Comparison of Best Results of MS & P6 between Best Results of Heuristic Results for 30 Activities

30 Activities		Project Duration (Days)		
ID	Project Nr	Min MS-P6	Heuristic	Min MS-P6
		Duration	Results	% Deviation
1	187	57	57	0,00%
2	125	75	67	11,94%
3	455	62	57	8,77%
4	139	49	46	6,52%
5	201	90	84	7,14%
6	328	61	61	0,00%
7	209	74	69	7,25%
8	175	52	52	0,00%
9	461	58	58	0,00%
10	185	48	48	0,00%
11	166	63	63	0,00%
12	208	67	62	8,06%
13	136	37	35	5,71%
14	188	55	55	0,00%
15	6	50	48	4,17%

Table A-48: Comparison of Best Results of MS & P6 between Best Results of Heuristic Results for 60 Activities

60 Activities		Project Duration (Days)		
ID	Project Nr	Min MS-P6	Heuristic	Min MS-P6
		Duration	Results	% Deviation
1	376	86	86	0,00%
2	10	81	80	1,25%
3	3	71	68	4,41%
4	249	114	99	15,15%
5	387	68	68	0,00%
6	127	103	87	18,39%
7	445	123	106	16,04%
8	2	70	68	2,94%

Table A-48: Comparison of Best Results of MS & P6 between Best Results of Heuristic Results for 60 Activities (Continued)

60 Activities		Project Duration (Days)		
ID	Project Nr	Min MS-P6	Heuristic	Min MS-P6
		Duration	Results	% Deviation
9	406	151	134	12,69%
10	58	72	72	0,00%
11	123	105	88	19,32%
12	19	65	65	0,00%
13	224	83	83	0,00%
14	184	67	67	0,00%
15	450	129	114	13,16%

Table A-49: Comparison of Best Results of MS & P6 between Best Results of Heuristic Results for 120 Activities

120 Activities		Project Duration (Days)		
ID	Project Nr	Min MS-P6	Heuristic	Min MS-P6
		Duration	Results	% Deviation
1	31	78	74	5,41%
2	114	149	125	19,20%
3	209	115	102	12,75%
4	104	222	196	13,27%
5	316	148	128	15,63%
6	478	128	116	10,34%
7	157	218	186	17,20%
8	433	107	107	0,00%
9	472	129	113	14,16%
10	406	118	113	4,42%
11	67	133	118	12,71%
12	479	143	113	26,55%
13	227	104	104	0,00%
14	216	103	103	0,00%
15	357	253	208	21,63%