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Optimization of multiple resources for multi-projects

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Optimization of Multiple Resources for Multi-Projects

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Sarah Aboul Fotouh

Abstract

Optimization of resources is very important in all construction projects. Project managers have to face problems regarding management of cost, time and available resources for single projects. This is more challenging when managing multiple projects. Most of the recent studies focused on optimization of resources for a single project, or a single resource. This thesis presents a numerical model of multiple resources optimization for multiple projects using Genetic Algorithm. Most of the companies in the construction industry optimize the resources for single projects only. However, with the presence of several mega projects in several developing countries running at the same time, there is a need for a model to enhance the efficiency of available resources, and decreases the fluctuation as much as possible and try to maximize the use of the available pool of resources. The proposed model is user friendly, and it can optimize up to nine resources in three different projects running at the same time. The model is used on the identified critical resources. It calculates the cost of each resource, minimize the cost of extra resources as much as possible and generate the schedule of each project within a selected overall program. The model was verified by different scenarios; 1- optimization of multiple resources of a single project; 2- optimization of single resource of multiple projects; 3- optimization of multiple resources of two projects; 4- optimization of multiple resources of three projects meeting deadlines; 5- optimization of multiple resources of three projects but extending the deadlines. The model was able to decrease the extra cost of resources significantly in all scenarios. To validate the model a case study of several

residential villas was chosen to test the model on real projects and the extra cost of resources was reduced significantly without extending the projects time.

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List of Abbreviations:

PM	Project Manager
MP	Multiple Projects
GA	Genetic Algorithm
EA	Evolutionary Algorithm

Chapter 1: Introduction

1.1- Background

Project Management Institute defines project management as "the application of knowledge, skills, tools and techniques to a broad range of activities in order to meet the requirements of a particular project" [1]. Any project has five main processes that overlaps together as shown in Figure 1:

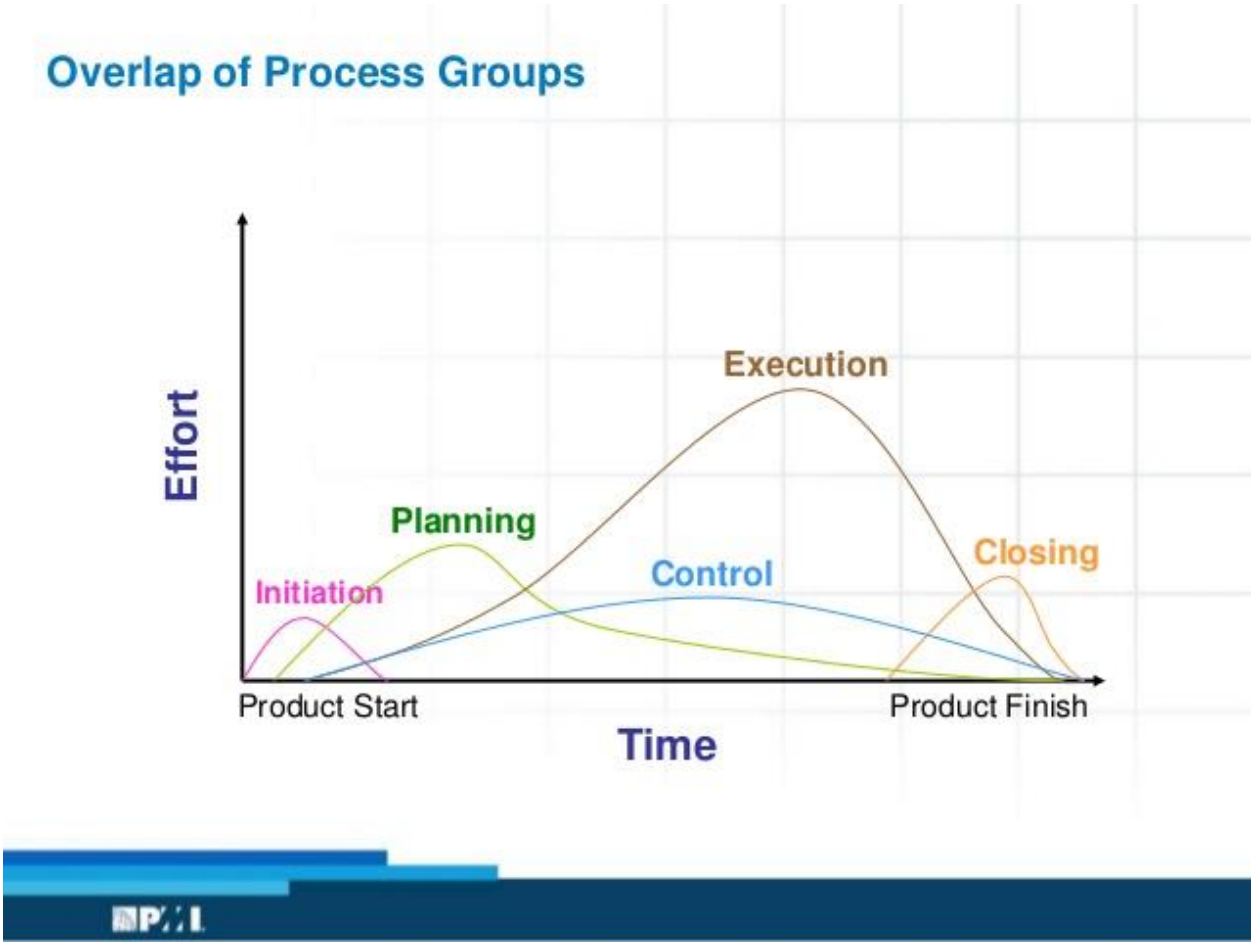


Figure 1 Overlap of Project Management Processes Graph [2]

1- Initiation: It involves starting up a new project by defining its objectives, scope, purpose and deliverables to be produced.

2- Planning: It is when you start to plan time, cost, and resources adequately to estimate the work needed and to effectively manage risk. This process continues till the end of the project, as there will always be updates to the original (base) plane according to day-to-day circumstances.

3- Execution: It involves coordinating people and resources, as well as integrating and performing the activities of the project in accordance with the project plan.

4- Control: Project managers will compare project status and progress to the actual plan, as resources perform the scheduled work. During this phase, project managers may need to adjust schedules or do what is necessary to keep the project on track. This process continues till the end of the project.

5- Closure: After project tasks are completed and the client has approved the outcome, an evaluation is necessary to highlight project success and/or learn from project history.

The above five processes are for a single project. The project manager is mainly concerned with coordination and integration between activities using the available pool of resources for the project. Managing multiple projects (MP) is usually more challenging, as the projects manager (PM) has greater responsibilities and the 5 processes are multiplied by the number of projects. The PM has to coordinate between all the projects and has to maximize the efficiency of resources with the least possible cost [3].

Resources management is one of the most challenging problems that faces any project manager. In the literature, there has been many studies that tried to solve this problem using heuristic

methods and meta-heuristic methods [4]–[10]. Most of them were focused on decreasing the fluctuation of using the resources, without considering the different costs of each resource into the equation.

All of the studies addressed resource leveling compared their results of GA models with Heuristics models and all of them proved that GA was more flexible and gave better results for single project [11], [12]. Most of GA studies focused on three aspects in resource allocating:

- Allocating of a single resource in a single project.
- Allocating of multiple resources for a single project.
- Allocating of single resource for multiple projects.

Few of the studies addressed focused on how to level multiple resources within a company's entire profile, not only within a specific project using fuzzy logic [3], [13].

1.2 Problem Statement

The rate of growth of construction industry increases annually. To cope with this growth, more studies are needed to solve more complex problems as the complexity increases every day. Most of construction companies now are keen to save resources as much as possible to decrease the total cost of the project, especially when they are involved in more than one project and the projects are sharing the resources. Optimization of resources became necessary to solve this problem. After optimization, the contractor should know when and where to use each resource, and try to minimize importing more expensive resources from outside the company.

1.3 Scope of Work

This thesis utilizes a GA based model that will study cost optimization and resource allocation of multiple resources for multi-project management. The model takes into consideration the maximum pool of available resources, and time constraints.

The maximum total number of resources to be allocated in the model is 9 resources. They are divided into three categories; namely:

i- Human Resources: HR_1, HR_2, HR_3

ii- Equipment Resources: ER_1, ER_2, ER_3

iii- Material Resources: MR_1, MR_2, MR_3

Each category has three different resources. The resources to be included in the model should be the resources that have the highest effect on the total cost of the project, not necessary be three resources of each category. These three category were chosen as they are the main components of direct cost of any project. The indirect cost is not taken into consideration as the model does not aim to change the project's given durations, so the indirect cost will not differ. The model is tested on three different projects running simultaneously, and they share the nine resources to be allocated.

1.4 Research Methodology

This research started with reading literature in different fields in project management area such as multiple project management, resources management, optimization of resources, and its associated costs. A flow chart of the research methodology is shown in Figure 2 below, which illustrates the sequence of the methodology of this research.

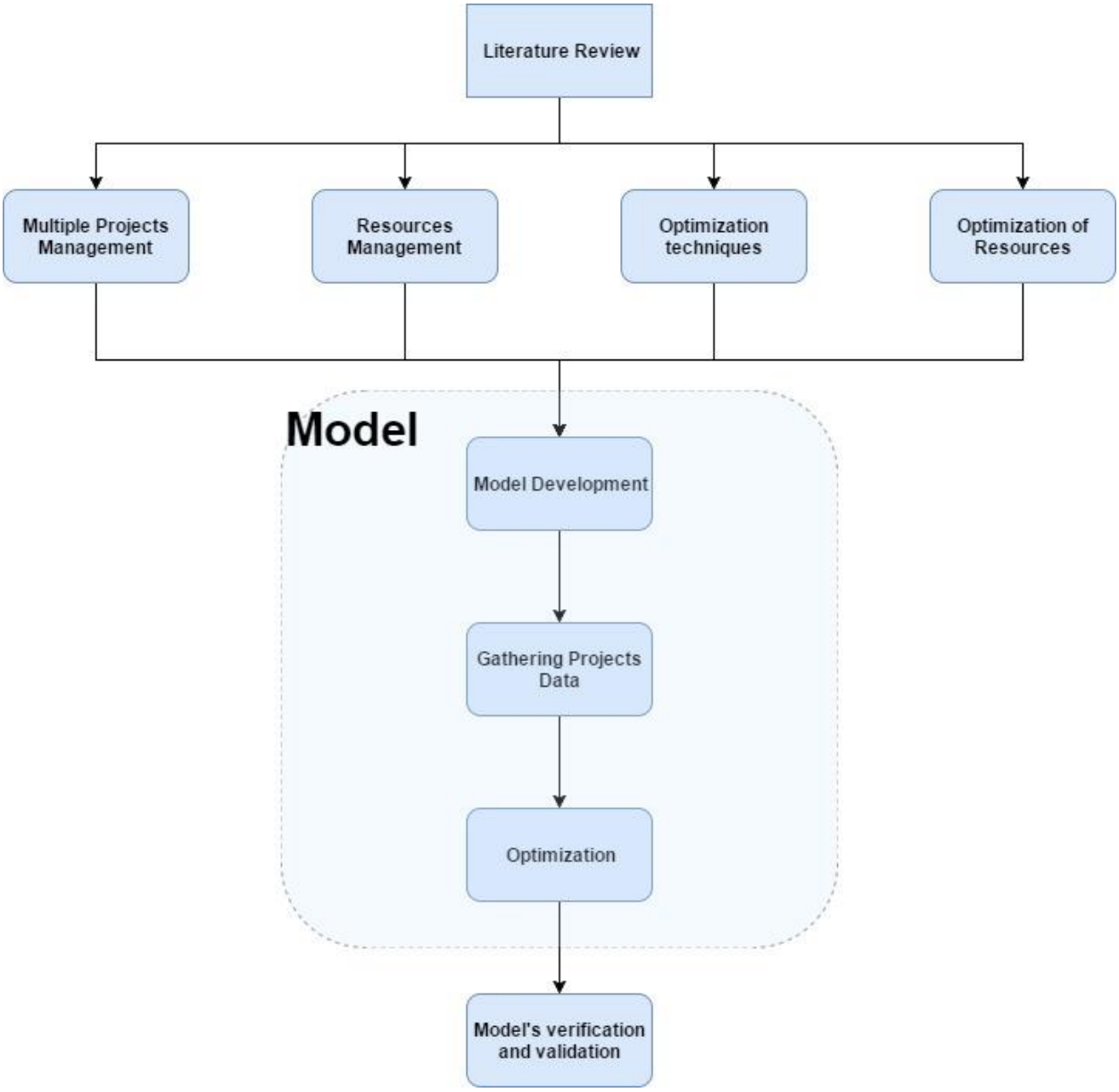


Figure 2 Research Methodology Flow Chart

1.5 Thesis Organization

This thesis is divided into six chapters and then the references. The first chapter is the introduction, followed by scope of the research, research's methodology, and finally the organization of the thesis.

The second chapter is literature review which is divided into five sections:

1- Managing Multiple Projects.

2- Managing Resources.

3- Optimization techniques.

4- Optimization of Resources.

5- Gap in the Literature.

Third chapter is Model Development. This chapter explains how the model was developed, its constraints, variables, objective function, and finally how is the model built. A flow chart was generated to illustrate the sequence.

Fourth chapter is Verification of the Model. In this chapter the model was tested for a single project multiple resources optimization, single resource optimization for all three projects, optimization of resources for two projects, optimization of resources for three projects and finally optimization of resources for three projects allowing extension of time. Results were obtained and sensitivity analysis was done.

Fifth chapter is the case study, where the model was tested on a real data that was obtained from a mega project based in Cairo.

The sixth, and last chapter is the Conclusion and Recommendation. The conclusion states the model's outcome, findings and who will use it. And then a list of recommendations for future studies.

Chapter 2: Literature Review

2.1- Managing Multiple Projects

With the increase in the world population, construction industry is growing rapidly to fulfill the needs of the population. As the industry grows, and a proper management is needed. The modern engineer is faced daily with multiple challenges. The challenge has been there for 20 years or more as Rosenau [14] states that project objectives must focus on accomplishing the "triple constraints" of performance specification, time schedules and cost budget simultaneously. He views the project lifecycle as consisting of a number of key activities, namely the definition of project objectives, formulation of the project plan, leading and monitoring plans for implementation and finally project completion. As part of their analysis of project management, Leintz and Rea [15] identify a number of characteristics that affect project success.

These are:

- The clarity of project objectives.
- The fit between a project's scope and the objectives it tries to achieve.
- The strong relationship of all projects with the standard structure of the company.
- The identification and proper management of potential difficulties early in a project.
- Maintaining a small, effective project implementation team that possesses the necessary skills to achieve the project objectives.

As a portfolio of projects is a collection of individual projects, the above issues remain highly relevant when managing multiple projects.

As managing a single project is difficult, the situation becomes more challenging when there are multiple projects ongoing concurrently within an organization. Projects needs to be viewed as an integrated portfolio rather than a separate projects. In managing multiple projects, the project manager is required to maintain control over a different types of construction projects, balance conflicting requirements of resources and coordinate the project portfolio to ensure the optimum outcome for the organization is achieved.

The main challenges that has to be addressed when managing multiple projects according to Turner and Speiser [16] are:

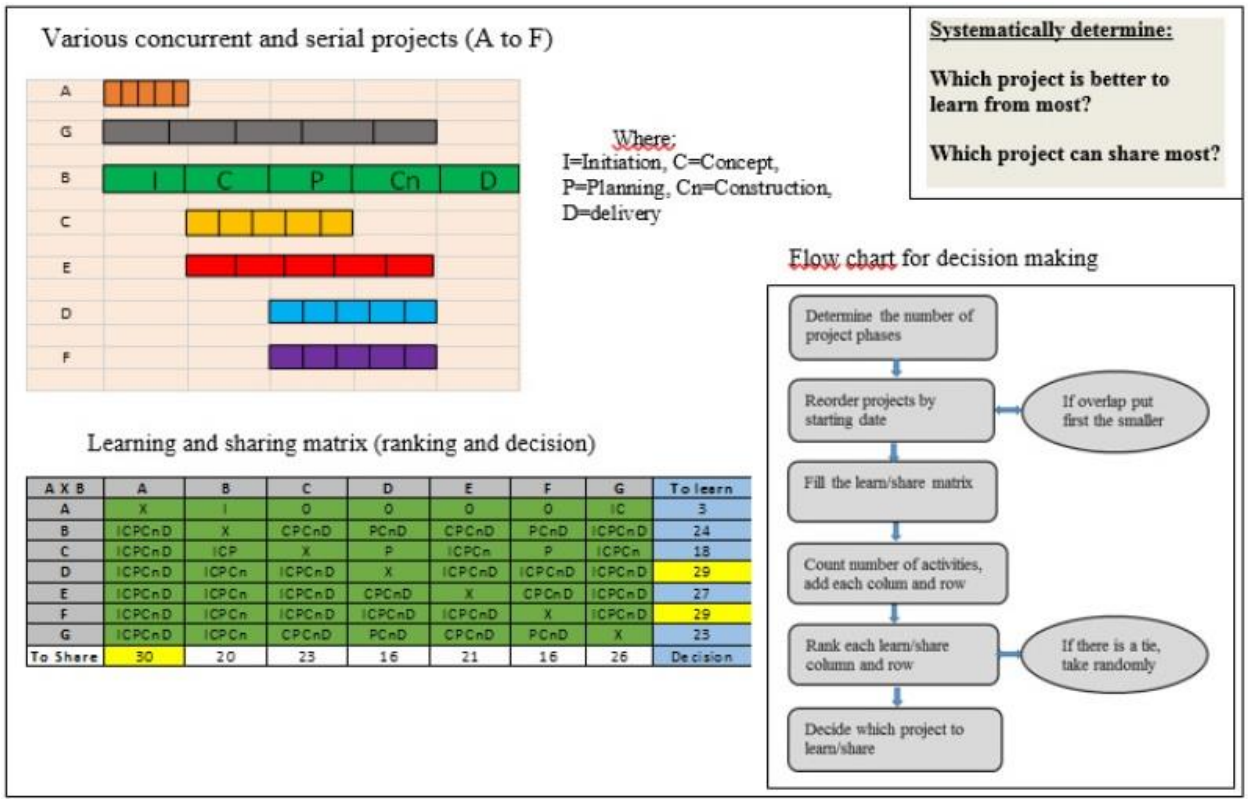
- Projects are overlapping with other projects and day-to-day operations, sharing common deliverables, resources, information or technology across those overlapping projects.
- Prioritization of resources on daily basis over all running projects.
- Meeting the deadlines of the projects, which contribute to the overall development objectives of the parent organization.

On the other hand, Dooley and O'Sullivan [17] discussed the main reasons of failure in managing portfolios within an organization as follow:

- Poor leadership and direction;
- Poor alignment between goals and projects;
- Poor monitoring of holistic process results; and
- Poor planning and control of action implementation.

Another problem at the core of managing multiple projects is that many organizations find it difficult to improve the process as they fail to learn from their past errors. The reuse of existing organizational knowledge, which gained through experience, can greatly reduce the time spent on problem solving and increase the quality of work. Construction projects can learn from within the same company or outsiders, and from both small/large projects of shorter/longer project life spans. [18]

Belay et al [3] made a study that focused on learning/sharing the knowledge experience in different sized multiple construction projects. They developed a hypothetical learning and sharing matrix as shown in Figure 3.



A X B	A	B	C	D	E	F	G	To learn
A	X	I	O	O	O	O	IC	3
B	ICPCnD	X	CPCnD	PCnD	CPCnD	PCnD	ICPCnD	24
C	ICPCnD	ICP	X	P	ICPCn	P	ICPCn	18
D	ICPCnD	ICPCn	ICPCnD	X	ICPCnD	ICPCnD	ICPCnD	29
E	ICPCnD	ICPCn	ICPCnD	CPCnD	X	CPCnD	ICPCnD	27
F	ICPCnD	ICPCn	ICPCnD	ICPCnD	ICPCnD	X	ICPCnD	29
G	ICPCnD	ICPCn	CPCnD	PCnD	CPCnD	PCnD	X	23
To Share	30	20	23	16	21	16	26	Decision

Figure 3Learning and sharing matrix [3]

Another common challenge multiple project managers face, is the change of scope of the project. Change of scope could be due to modifications in the project (expansion) or because of unforeseen conditions that require additional activities and resources. Managing both type of changes need real time decisions, flexibility, and optimization of resources.[3]

2.2- Resources Management

Resources management is the process of using a company's resources in the most efficient possible way. The main resources in construction industry are divided into three main groups known as the 3Ms:

- Man Resources
- Material Resources
- Machinery Resources

Resource management play an important role in project management, in which the project manager tries to avoid unnecessary resources overload. There are three objective functions well established in the literature to cope with resource allocating [19]:

- The minimum moment has to be minimized;[20]
- The *total overload cost problem*, where costs are generated when the pool of a given resource is exceeded [10];
- The *total adjustment cost problem*, where one is concerned with the minimization of the cumulative costs arising from increasing or decreasing the utilizations of resources.[9]

2.3- Optimization Methods

Optimization became essential in improving the efficiency and ensuring the economic feasibility of many applied systems in the construction industry. Throughout the years, with the technological development of computing systems and the need for optimization techniques, several sophisticated optimization systems were developed to solve many difficult problems that were hard to solve such as:

1- Analog Methods: By using physical methods, electrical analogs and dual series, but this method is not always possible [1].

2- Analytical Methods: By using mathematical models, but it is not feasible for solving large scale projects [1]

3- Heuristic Methods: By using computers, the solution is generated heuristically by using specific equations [1], so they cannot be applied to all construction projects [3].

4- Genetic Algorithm (GA) Methods: It is a general purpose optimization method that is based on genetic science [1].

In 1975, John Holland [21] developed genetic algorithms (GAs) simulating the Darwinian principle of evolution and the survival of the fittest [21]. Many algorithms followed, adjusting the original methodology, to overcome the limitations revealed in the inability to reach optimal solutions or near optimal solutions within a reasonable time. In 1989, Pablo Moscato developed the "memetic algorithm (MA) model was based also on the Darwinian principle of evolution" [22], but his main contribution based on adopting "Dawkins' concept of a meme" [22]. Other evolutionary algorithms (EAs) were also developed to simulate natural phenomena like for instance, particle swarm optimization, ant colony optimization, and shuffled frog

leaping. EA acts as an adequate solution for construction industry to find a near optimum solution within a reasonable time [2].

Evolutionary algorithms (EAs) are stochastic search methods that mimic the natural biological evolution and/or the social behavior of different species. Such algorithms have been developed to arrive at near-optimum solutions to large-scale optimization problems, when precision is not the highest priority and the optimal solution would be exhaustive or difficult to find. [23]

The first evolutionary-based technique introduced in the literature was the genetic algorithms (GAs)[21][21]. GAs were developed based on the Darwinian principle of the 'survival of the fittest' and the natural process of evolution through reproduction[21]. There are other evolutionary algorithms (EA) that were introduced in the past 20 years and Figure 4 shows a schematic diagram of the natural processes that the five algorithms mimic such as:

1- Memetic Algorithm (MAs) [22],
2- Particle Swarm Optimization (PSO),
3- Ant colony Systems,
4- Shuffled Frog Leaping (SFL) [23].

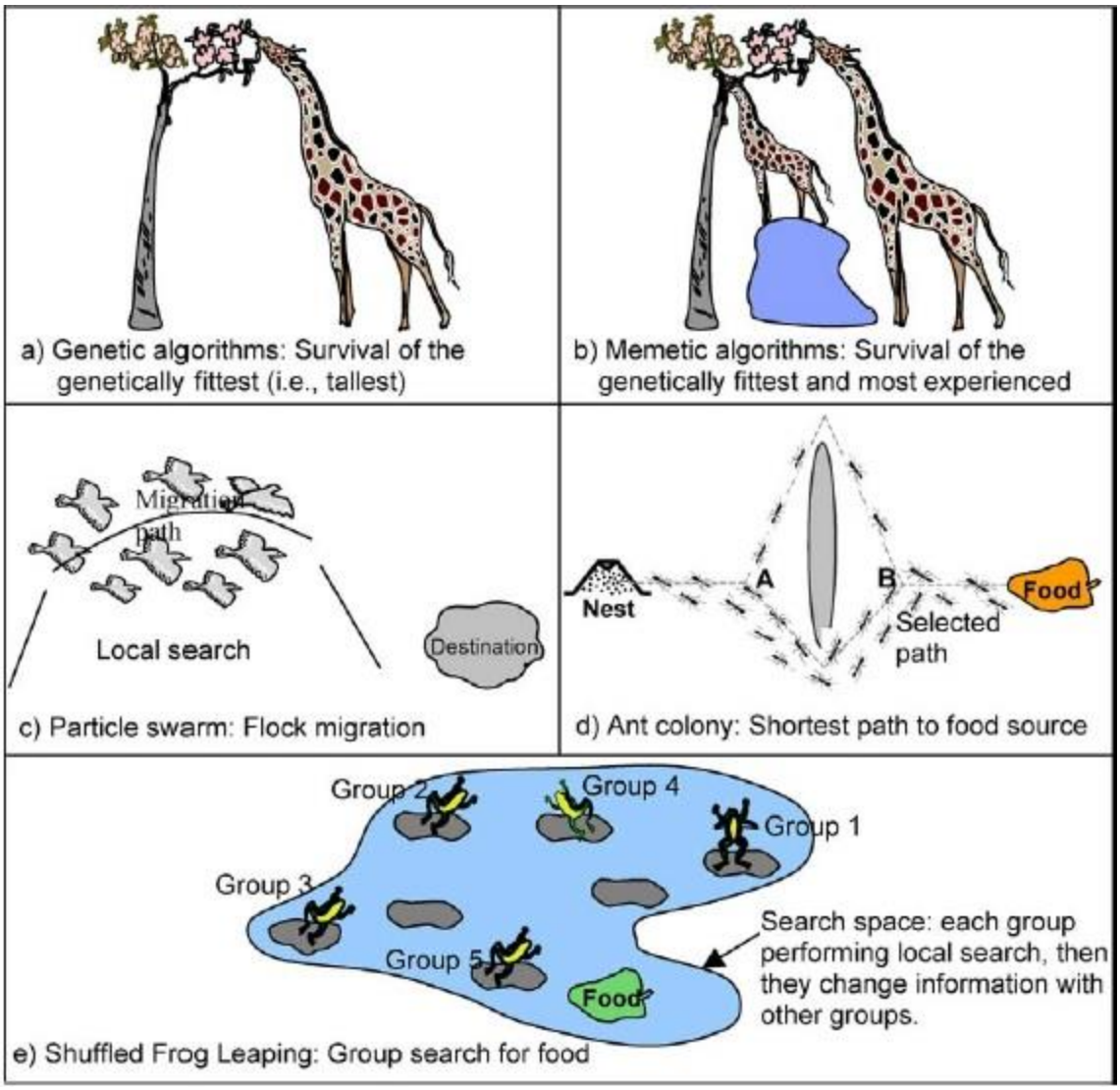


Figure 4 "Schematic diagram of natural evolutionary systems." [23]

The EA applications in construction management are numerous and involve the research areas of repetitive and linear project scheduling, resources scheduling, time-cost trade-off, site layout, finance-based scheduling, project control, prediction of the risk of contractor default and project success, earthmoving operations, resource utilization, precast production scheduling, cost and duration estimating, equipment selection and financial management. Genetic algorithms are the most widely used meta-heuristics in civil engineering and construction management areas.

2.4.1 Genetic Algorithm

Genetic algorithm (GA) is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that mimics the natural biological evolution and social behavior of species through the survival of the fittest [23]. This metaheuristic is used to generate feasible solutions for optimization problems by natural evolution, such as inheritance, mutation, selection, and crossover [24].

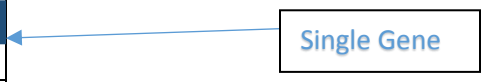
Population:

They are candidates of feasible solutions to an optimization problem that are continuously evolved toward better solutions.

Each feasible solution is called a chromosome and each chromosome is made up from number of genes. Each gene is a variable. Table 1 illustrates the population.

Table 1 Genetic Algorithm population illustration

Population					
Chromosome 1	1	4	5	4	1
Chromosome 2	0	5	1	5	0
Chromosome 3	1	1	0	1	1
Chromosome 4	0	0	1	0	2
Chromosome 5	1	1	0	1	1
Chromosome 6	2	0	6	0	2
Chromosome 7	1	6	8	6	3
Chromosome 8	2	8	9	8	7
Chromosome 9	3	9	5	9	9



Operations:

1- *Selection:* Genes are randomly selected to reproduce a feasible solution (chromosome) to the problem

2- *Cross over:* It is the process of reproduction of new chromosomes from currently fitted parents by crossing over the genes of the parents to the off springs randomly but with preference towards the fitter parent.

3- *Mutation:* Chromosomes that are less likely to survive due to their low relative fitness may be mutated to a fitter function. In this process, the chromosomes' genes are altered in an effort to reach fitter chromosomes. The mutation is only bias towards selecting fitter parents to mutate whereas the new value of the altered gene is randomly selected. Unlike crossover which resembles the reproduction in natural evolution, mutation is a sudden generation of a chromosome that rarely takes place similar to what happens naturally. "Mutation is a complementary process to the crossover since it helps the algorithm avoid getting trapped in any local minimums. The local minimum is perceived as the solution whereas the global minimum is the near optimum one. The same applies for the local and global maximums."[25]

2.5- Previous Models

Many researches have been done on resource allocating, with different approaches. Harris [20] developed one of the earliest simple heuristic process called the "Minimum Moment algorithm" for the resource leveling problem. Later, Hiyassat [26] modified Harris's process by taking into consideration the activities' free float and the resources needed in the selection criteria. Easa [10] was the first one; up to my knowledge; to make an optimization model for resource leveling. The main objective of Easa's [10]model was to minimize the deviations between the actual and desirable resource rates.

Also, Ramlogan and Goulter [27] proposed a mixed integer model to level resources for project scheduling. The model itself had three global objectives:

1. The overall resource allocating on the project.
2. The resource allocating of individual activities (internal allocating).
3. The minimization of the total duration of the individual activities, i.e. to try to make each activity occur on consecutive days.

These objectives are placed within the formulation in a weighted multi-objective framework.

Son and Matilla [28] had presented different approach. They allowed splitting of activities to level the resources. Hariga and El-Sayegh [29] formulated as a mixed binary–integer programming to minimize the costs associated with the splitting of the non-critical activities.

In addition to the above exact formulations for the resource leveling problem, several authors proposed meta-heuristic procedures to generate near-optimal schedules. Senouci and Eldin [30] proposed a model based on genetic algorithm (GA) for resource scheduling. This model performs resource leveling along with resource allocation simultaneously. In a recent paper, Liao et al. [31] provided a comprehensive review of previous research works using meta-heuristics to address project management problems and issues. Leu et al. [32] proposed a GA based optimization system to minimize the weighted total deviations of resources' requirements. Al Sayegh et al [29] came up with an integrated meta-heuristic search procedure by combining PSO with simulated annealing for the multi-resource leveling problem with activity splitting (MRLP-AS) and considering a cost instead of a utilization based objective function.

2.6- Gap in the Literature

Most of the previous studies were on allocating a single resource only for a single project or a single resource for multiple resources using different algorithms. Few studies were made on multiple resources for a single project. Fewer studies were made on multiple resources of multiple projects using fuzzy logic [33] and cost was not taken into consideration. None of the studies in the literature; up to the author's knowledge; were made on allocating multiple resources of multiple projects and try to minimize the extra cost of resources needed. This thesis will discuss generating; using genetic algorithm; a model to optimize the cost of extra resources and re- allocate the resources according to the new schedule generated. The model is user friendly, which can be used by any project manager without buying any special software.

Chapter 3: Model Development

The model in this thesis is based on Genetic Algorithm. It consists basically of an initial population that evolves through a number of iterations. The outcome solution is called *Chromosome* and is represented by set of integer values called *Genes.*

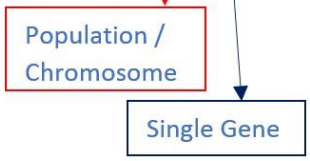
The initial population is generated randomly, then the fitness is calculated for all possible solutions and the following operators are performed:

- Selection,
- Crossover
- Mutation Operator.

The chromosome of this model is the number of days to be shifted for each non-critical activity as shown in Table 2. Of course, the critical path may change after each iteration, but the total duration of the project remains the same if the user wants it to meet the deadline, or he might extend the deadline if the user wants to [34].

Table 2 Illustration of Model's Chromosome

Activity ID	Start	Finish	Duration (Months)	Predessor	HR1	HR2	HR3	ER1	ER2	ER3	MR1	MR2	MR3	Shifting days
1000	1	5	4	0	2	0	0	1	0	2	2	1	3	0
1001	1	4	3	0	2	0	0	1	0	2	2	1	3	0
1002	6	8	2	1000	2	0	0	1	0	2	2	1	3	0
1003	5	6	1	1001	2	1	0	1	0	2	1	1	0	0
1004	9	12	3	1002	0	0	0	1	0	2	3	2	1	0
1005	7	10	3	1003	0	0	0	1	0	2	1	2	3	0
1006	13	14	1	1004	0	1	0	0	0	2	2	3	2	0
1007	11	13	2	1005	0	1	0	0	0	2	1	1	1	0
1008	15	16	1	1006	0	1	0	0	0	2	1	0	1	0
1009	14	15	1	1007	2	1	0	0	0	2	0	1	1	0
1010	17	21	4	1008	2	1	0	0	0	2	2	1	0	0
1011	16	19	3	1009	2	1	0	0	0	2	2	1	3	0
1012	22	24	2	1010	2	1	0	0	0	2	1	1	0	0



The quality of individuals (feasible solutions) is evaluated and ranked using a fitness function to minimize the total cost of resources [34].

3.1- Data Input Needed

The user has to input the following data for the model to be executed as shown in Table 3-Table 5:

(i) The start date and end date of each project (up to 3 projects). (Table 3)

Table 3 Screenshot of entering start date of each project

	Start Dates	End Dates
Project 1	1	46
Project 2	3	37
Project 3	5	51

(ii) The activities ID. (Table 4)

(iii) The predecessors of each activity. (Table 4)

(iv) The resources needed for each activity (up to nine resources). (Table 4)

(v) The duration of each activity.(Table 4)

Table 4 Screenshot of user's inputs of activities ID, resources required, predecessors and durations

					Human Resources			Equipment Resources			Material Resources		
Activity ID	Start	Finish	Duration (Months)	Predessor	HR1	HR2	HR3	ER1	ER2	ER3	MR1	MR2	MR3
1000	1	5	4	0	2	0	0	1	0	2	2	1	3
1001	1	4	3	0	2	0	0	1	0	2	2	1	3
1002	6	8	2	1000	2	0	0	1	0	2	2	1	3
1003	5	6	1	1001	2	1	0	1	0	2	1	1	0
1004	9	12	3	1002	0	0	0	1	0	2	3	2	1
1005	7	10	3	1003	0	0	0	1	0	2	1	2	3
1006	13	14	1	1004	0	1	0	0	0	2	2	3	2
1007	11	13	2	1005	0	1	0	0	0	2	1	1	1
1008	15	16	1	1006	0	1	0	0	0	2	1	0	1
1009	14	15	1	1007	2	1	0	0	0	2	0	1	1
1010	17	21	4	1008	2	1	0	0	0	2	2	1	0
1011	16	19	3	1009	2	1	0	0	0	2	2	1	3
1012	22	24	2	1010	2	1	0	0	0	2	1	1	0

(vi) Pool available for each resource (Pool). (Table 5)

(vii) Cost of resources within the pool (Reg. Cost). (Table 5)

(viii) Cost of resources that is above pool limit (Extra Cost). (Table 5)

Table 5 Screenshot of user's inputs of cost of resources and available pool

		Human Resources			Equipment Resources			Material Resources		
		HR1	HR2	HR3	ER1	ER2	ER3	MR1	MR2	MR3
Required		21	42	39	40	35	47	55	52	55
Pool		19	38	36	36	32	43	50	47	50
Extra		2	4	3	4	3	4	5	5	5
Reg. Cost		350	200	150	1,000	1,500	2,000	9,000	600	150
Extra Cost		455	260	195	1,300	1,950	2,600	11,700	780	195

3.1.1- Criteria to select the resources:

As mentioned before, the direct cost of any activity is divided into three categories:

1- Materials cost
2- Human resources cost
3- Equipment cost

The model can work up to 9 resources, three resources for each category or as the user's preference. The user should choose the resources with greatest difference in cost between the available pool cost and the extra resource cost or the resources which its pool is not that big and he will need to get more resources from outside.

Maximum of "Extra Cost of Resource – Cost of Available Pool"

3.2- Model's Constraints

There are two types of constraints in this model:

1- Hard Constraints: They are the constraints that cannot be broken.

   In this model there are three hard constraints which they are the deadlines for each project

2- Soft Constraints: They are the constraints that can be broken, but a certain penalty is added. In this model they are the extra resources needed. If the model cannot reach a

near optimum solution that all the resources needed are within the pool limit, then an additional cost will be added depending on which resource is exceeding the pool limit and its associated cost. The model will automatically select the resource with the least additional cost instead of the resource with the higher cost to minimize the cost as much as possible.

3.3 Model's Variables

The variable in this model is the number of days to be shifted for each activity. These variables will be added to the start date, so that the activity will be shifted by the number written in the variable cells.

Figure 5 Shows a screenshot of the variable cells from the model's excel file.

Shifting days
0
0
0
0
0
0
0
0
0
0
0
0
0
0

Figure 5 Variables cells Screenshot from the Model

3.4 Fitness Function

The fitness function or the objective function is to minimize the total extra cost of resources required greater than the available pool and is represented by the following equation [34]:

$$\sum_{i=1}^{3} EHRi * ECHRi + EERi * ECERi + EMRi * ECMRi \quad (1)$$

Where;

EHR: Extra Human Resources

ECHR: Extra Cost of Human Resources

EER: Extra Equipment Resources

ECER: Extra Cost of Equipment Resources

EMR: Extra Material Resources

ECMR: Extra Cost of Material Resources

Model's assumptions and limitations:

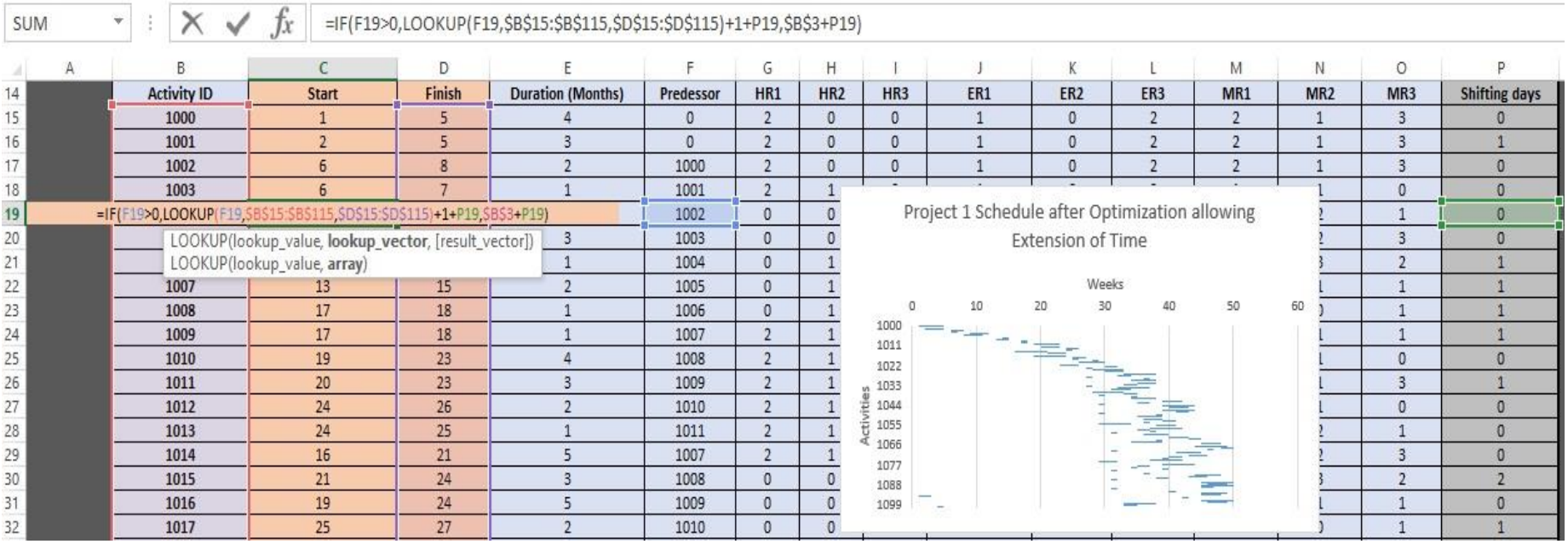
This model has few assumptions that the user has to take into consideration:

- The number of resources needed is constant throughout the activity period.
- The model can accommodate only one predecessor with Finish-to-Start Relationship, unless the user entered the start date manually.
- There is no limitation to the extra resources needed, but the model can be adjusted to limit the number of extra resources.
- The model minimize the direct cost only, because the indirect cost will not change as the duration of the projects does not change. But it can be adjusted to minimize the direct and indirect cost if the user wants to extend the time of any project.

3.4 Model built up using Excel 2013

3.4.1 Generating the Schedule

The model links the start of each activity to the end of its predecessor, so that it does not begin till the following day of the end of its predecessor. This link is a simple IF function in Excel 2013 as shown in Figure 6. A bar chart schedule is then formed.



Activity ID	Start	Finish	Duration (Months)	Predessor	HR1	HR2	HR3	ER1	ER2	ER3	MR1	MR2	MR3	Shifting days
1000	1	5	4	0	2	0	0	1	0	2	2	1	3	0
1001	2	5	3	0	2	0	0	1	0	2	2	1	3	1
1002	6	8	2	1000	2	0	0	1	0	2	2	1	3	0
1003	6	7	1	1001	2	1							0	0
1004				1002	0	0							1	0
1005			3	1003	0	0							3	0
1006			1	1004	0	1							2	1
1007	13	15	2	1005	0	1							1	1
1008	17	18	1	1006	0	1							1	1
1009	17	18	1	1007	2	1							1	1
1010	19	23	4	1008	2	1							0	0
1011	20	23	3	1009	2	1							3	1
1012	24	26	2	1010	2	1							0	0
1013	24	25	1	1011	2	1							1	0
1014	16	21	5	1007	2	1							3	0
1015	21	24	3	1008	0	0							2	2
1016	19	24	5	1009	0	0							1	0
1017	25	27	2	1010	0	0							1	1

Figure 6 IF function used to generate the schedule

3.4.2 Generating the histograms

Then the number of each resource is automatically sent to another section; using another IF function as shown in Figure 7 ; to create the bar chart of each resource needed each unit of time. A bar chart for each resource is then formed by adding the number of each resource needed in each unit of time.

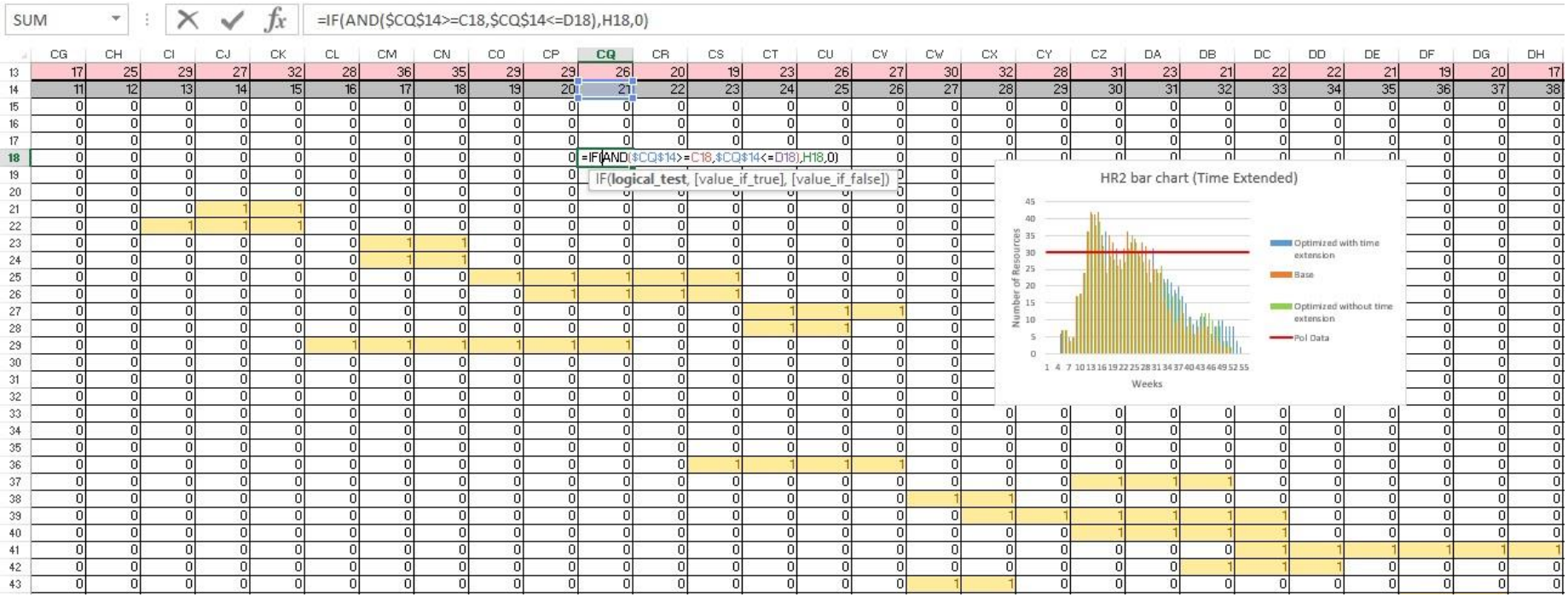


Figure 7 IF function used to generate the barchart

3.4.3 Calculating the Cost

The cost of resources is then calculated by multiplying the total number of resource of each unit time by the regular cost of the resources IF the number is below the available pool.

But if the total number of resources is above the pool limit, then the pool limit is multiplied by the regular cost of resources and the extra resources is multiplied by the extra cost of resources. Figure 8 shows a screenshot of the Model and the function used to calculate the cost.

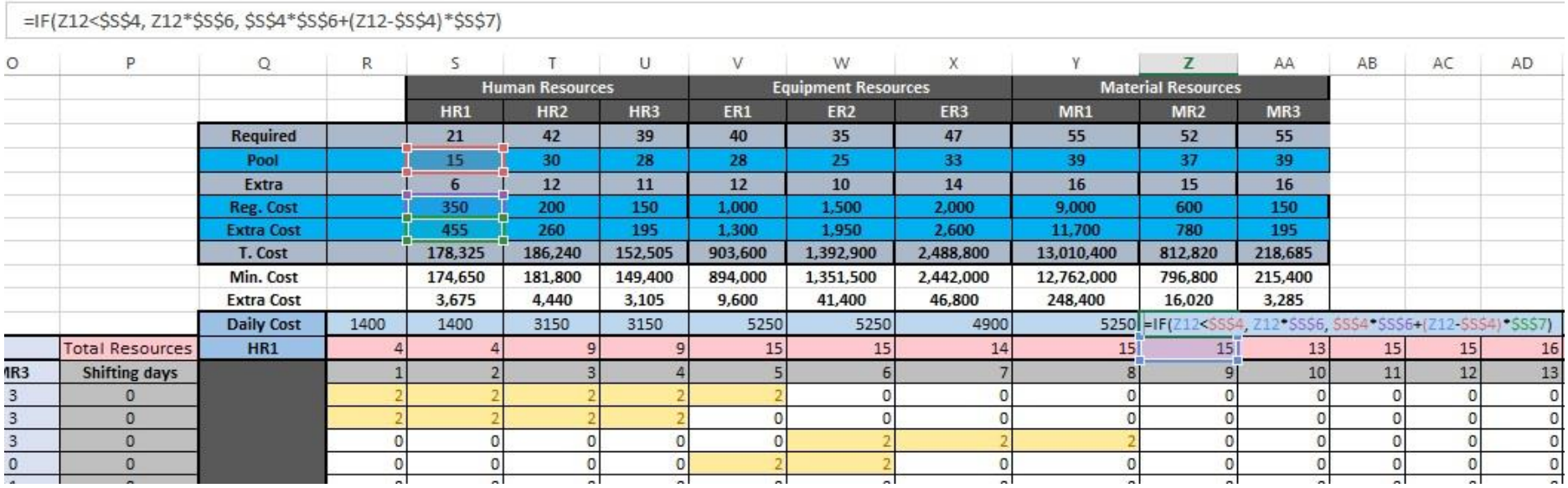


Figure 8 IF function to calculate the cost

3.5 Flow chart of the model's Genetic Algorithm

The model works genetically as explained in Figure 9 flow chart of the proposed algorithm, and the Evolver; a built-in tool in excel that is purchased; generates the population randomly, make cross over, selection, and/or mutation and continues the loop until a near optimum solution is reached.

An assumption was made that the number of resources needed is constant all over the activity period.

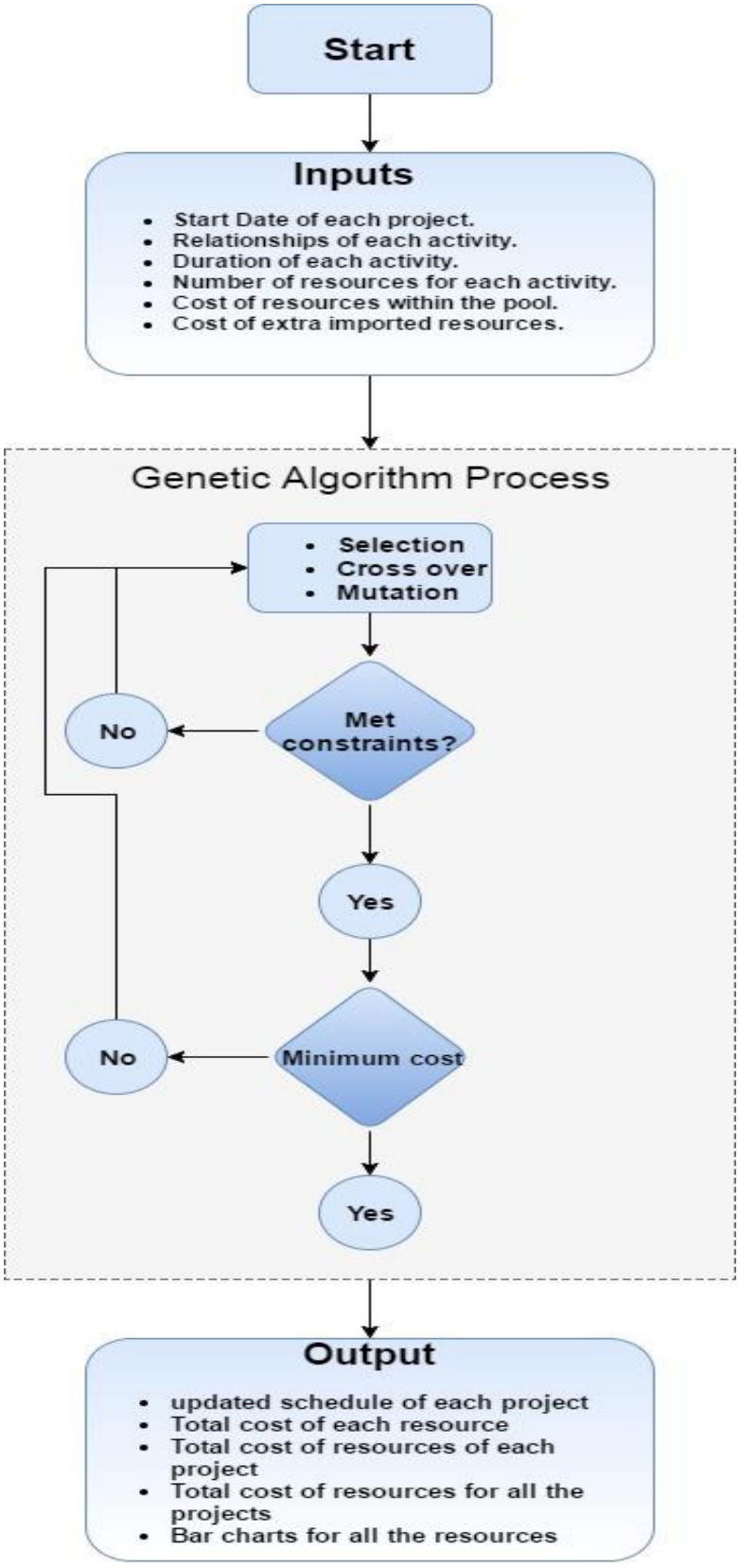


Figure 9 Flow chart of proposed algorithm

Chapter 4: Verification of the Model

The model was verified to test how it works with 5 different scenarios. The scenarios are:

1- Optimization of multiple resources of a single project.
2- Optimization of a single resource of 3 projects.
3- Optimization of multiple resources of 2 projects.
4- Optimization of multiple resources of 3 projects meeting deadlines.
5- Optimization of multiple resources of 3 projects extending the deadlines.

The pool of available resources was reduced by increments of 5% from the maximum number of resources needed as listed below, till it couldn't eliminate all the extra cost of resources:

- 10%
- 15%
- 20%
- 25%
- 30%

4.1 Multiple resources of Single Project

The model was tested on a single project with 9 resources without any extension of time. This would be helpful for a single project manager to decrease the cost of resources of a single project, and obtain the near optimum schedule. The base schedule of the project as shown in Figure 10 and the updated schedule after optimization of extra cost of resources as shown in Figure 11 show that there has been no change in the project's duration.

Although he extra resources cost increased as the pool of the available resources decreased, the model was able to eliminate all the extra costs of resources as shown in Figure 12 below, till the pool was reduced by 25%. But, when the pool was reduced by 30% the extra cost of resources was reduced by more than 99%. This might not be the case for all projects. The

model will act differently on different projects depending on the criticality ratio of the project and the number of resources available.

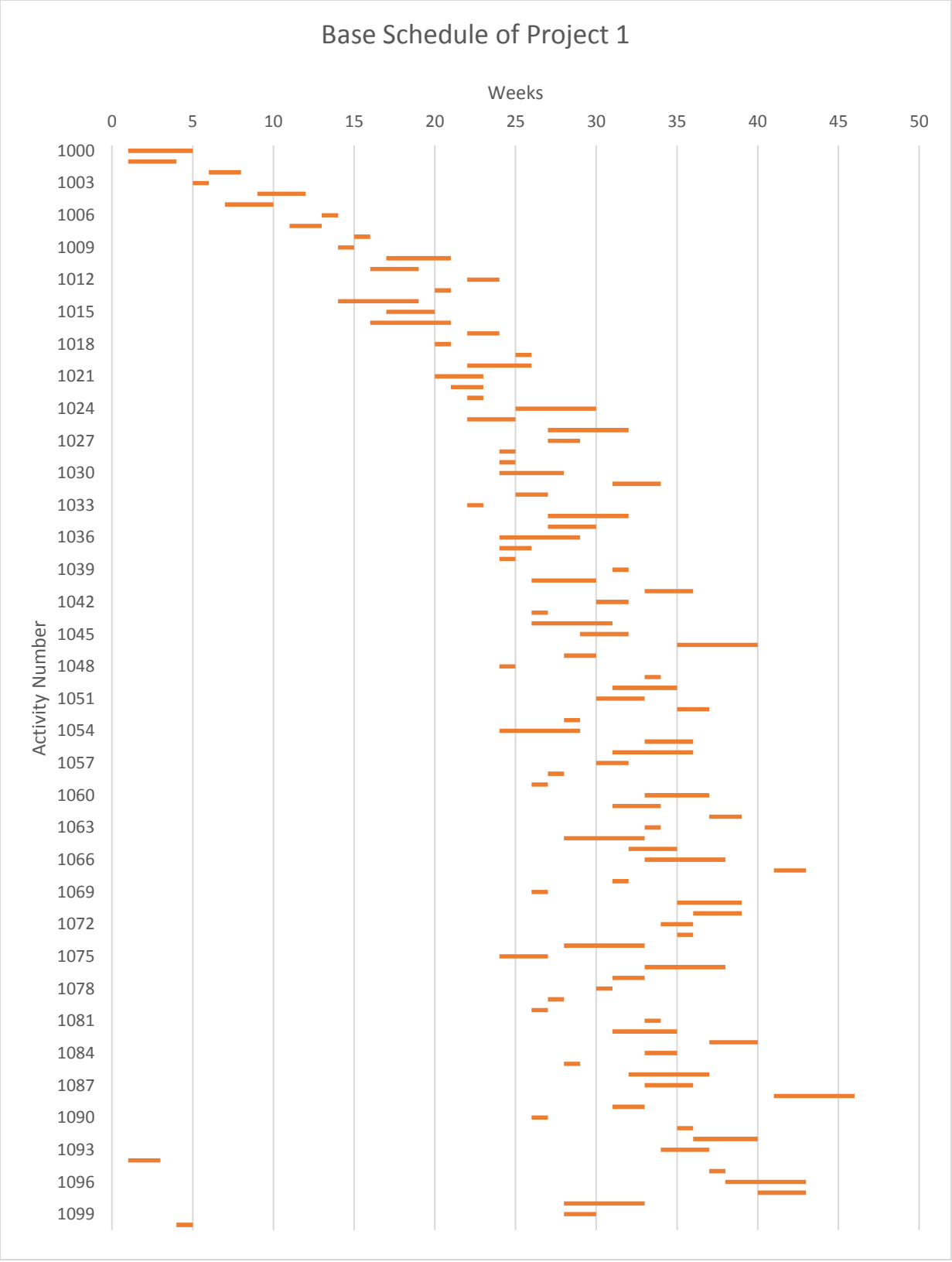


Figure 10 Base Schedule of Single project with Multiple Resources

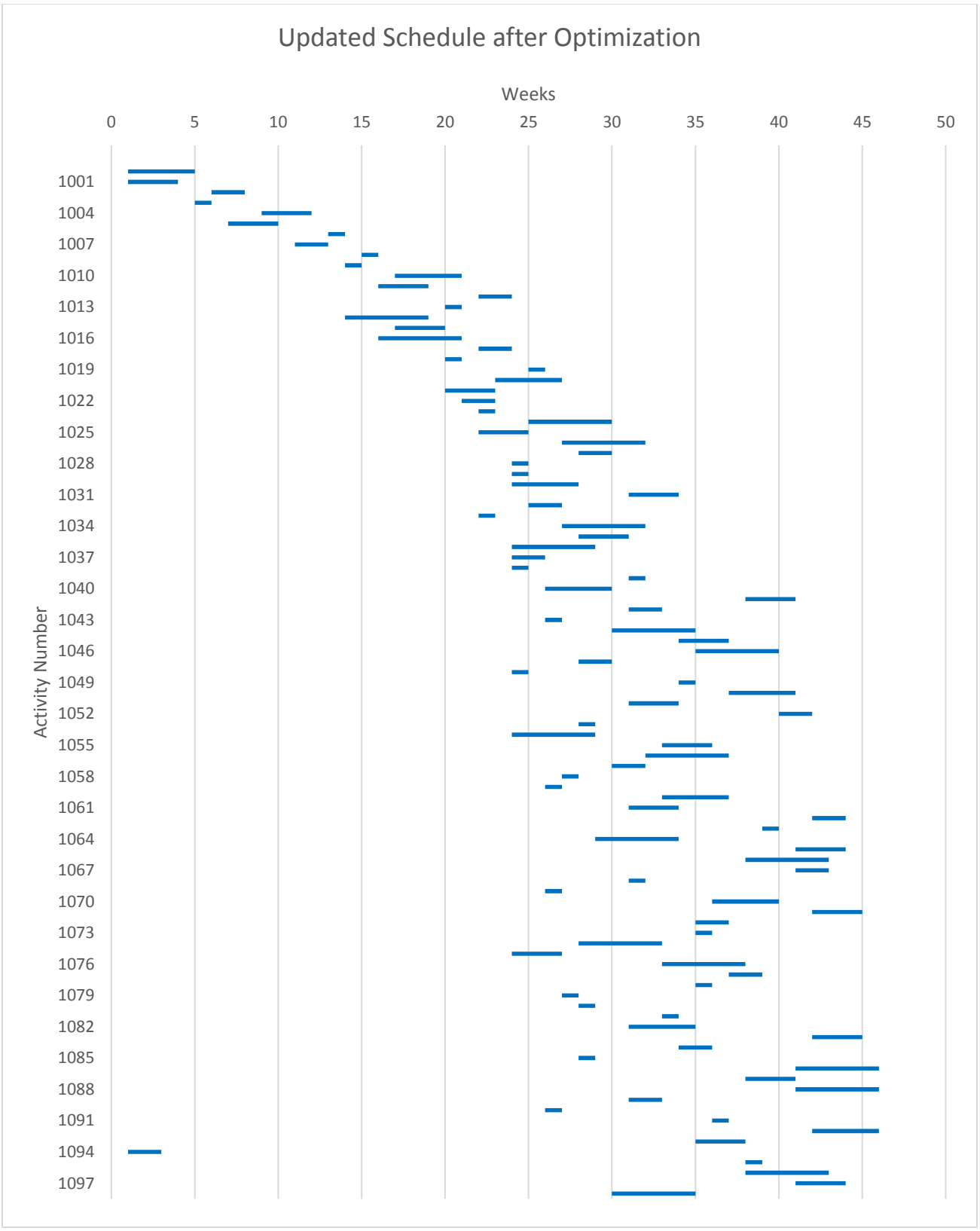


Figure 11 Updated Schedule of Single Project after Optimization

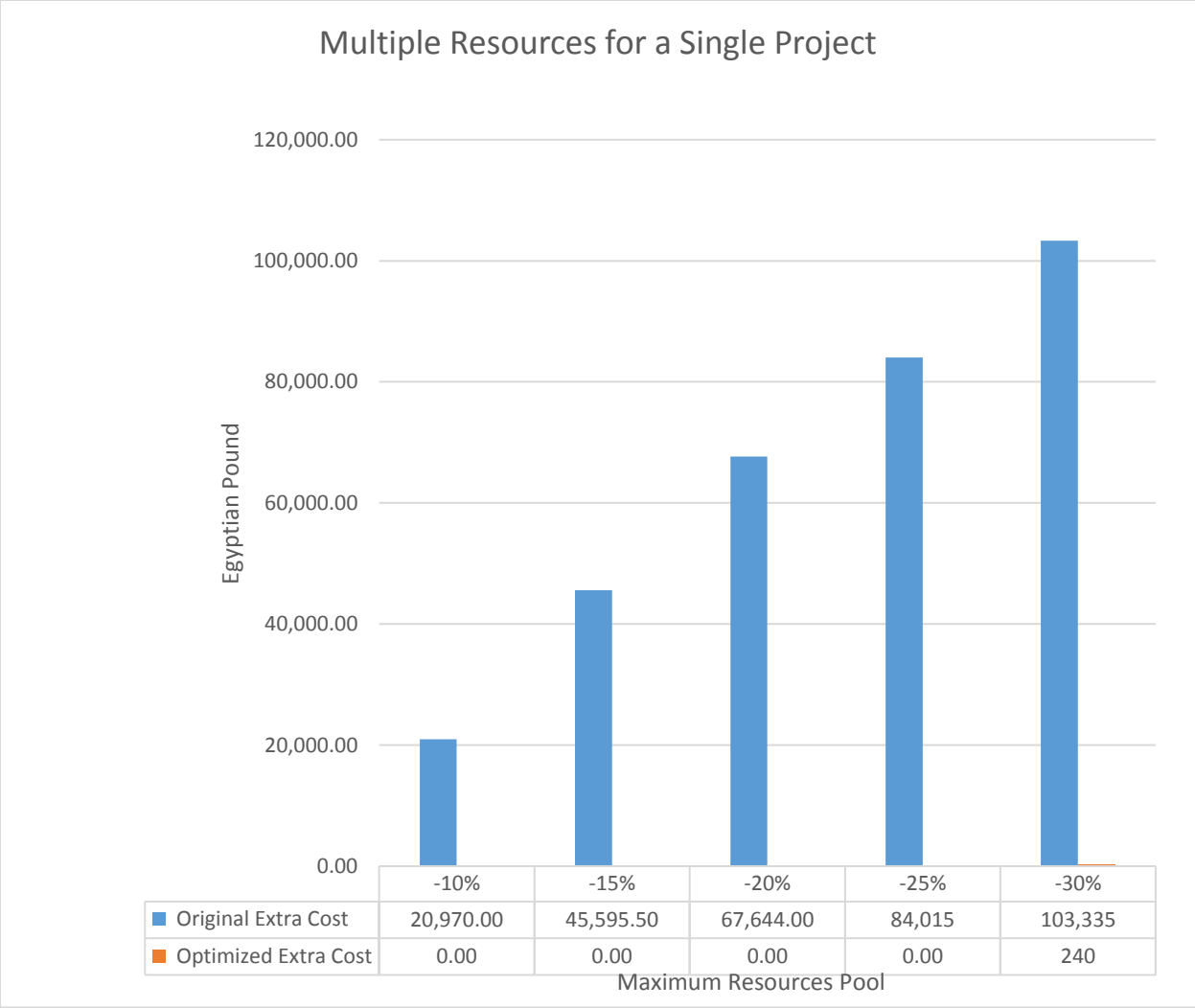


Figure 12 Extra cost of multiple resources for a single project

The bar charts of each resource are shown in Figure 13 - Figure 21 ; showing the number of resources needed before and after optimization for each week during the project's duration, when the number of available pool of resources is reduced by 30% of the original needed resources.

Figure 13 shows that the maximum number of HR1 needed before optimization was 8 in week #33, and 7 in weeks # 34-35, while the available pool is 6. After optimization, HR1 in week #33

was reduced by 50% to be only 4. In week #34 it was reduced to be 4 as well, and in week #35 it was reduced to 6. Therefore, all the extra cost of HR1 was eliminated after optimization.

Figure 14 shows that the maximum number of HR2 needed before optimization was 11 in week # 27, while the available pool is only 8. After optimization, the number of HR2 needed in week # 27 decreased to 8, but it increased in weeks #28-30 to 10 HR2, and in week #32 to 9 HR2. The maximum number of HR2 needed became 10 instead of 11, but the cost of extra HR2 decreased by more than 60%.

Figure 15 shows that all the extra cost of HR3 was eliminated when the pool was only 29 and the maximum number of HR3 decreased from 41 to 26.

Figure 16 shows that all the extra cost of ER1 was eliminated when the pool was 21. The maximum number of ER1 was reduced from 30 in week#35 to only 16 and the maximum number of ER1 after optimization became 19 and that was in week#36.

Figure 17 shows that all the extra cost of ER2 was eliminated. Before optimization the maximum number of ER2 needed was 23 in weeks #34-35. After optimization the maximum number of ER2 needed was reduced to 17 which is the pool limit.

Figure 18 shows that all the extra cost of ER3 was eliminated. Before optimization the maximum number of ER3 needed was 23 in weeks #32 and 35. After optimization the maximum number of ER3 needed was reduced to 17 which is the pool limit.

Figure 19 shows that all the extra cost of MR1 was eliminated. Before optimization the maximum number of MR1 needed was 33 in week #34. After optimization the maximum number of MR1 needed was reduced to 21 while the pool limit was 24.

Figure 20 shows that all the extra cost of MR2 was eliminated. Before optimization the maximum number of MR2 needed was 33 in week #33. After optimization the maximum number of MR2 needed was reduced to 20 while the pool limit was 24.

Figure 21 shows that all the extra cost of MR3 was eliminated. Before optimization the maximum number of MR3 needed was 32 in week #33. After optimization the maximum number of MR3 needed was reduced to 23 which is the pool limit.

All the resources exceeding the pool limit was decreased to meet the pool limit constraint, and some of them even went below the pool limit, except for HR2 as shown in Figure 14 in which few weeks exceeded the pool limit. It is noticed that most of the resources exceeded the pool limit were shifted towards the end of the project according to their available float so that the project's duration does not increase.

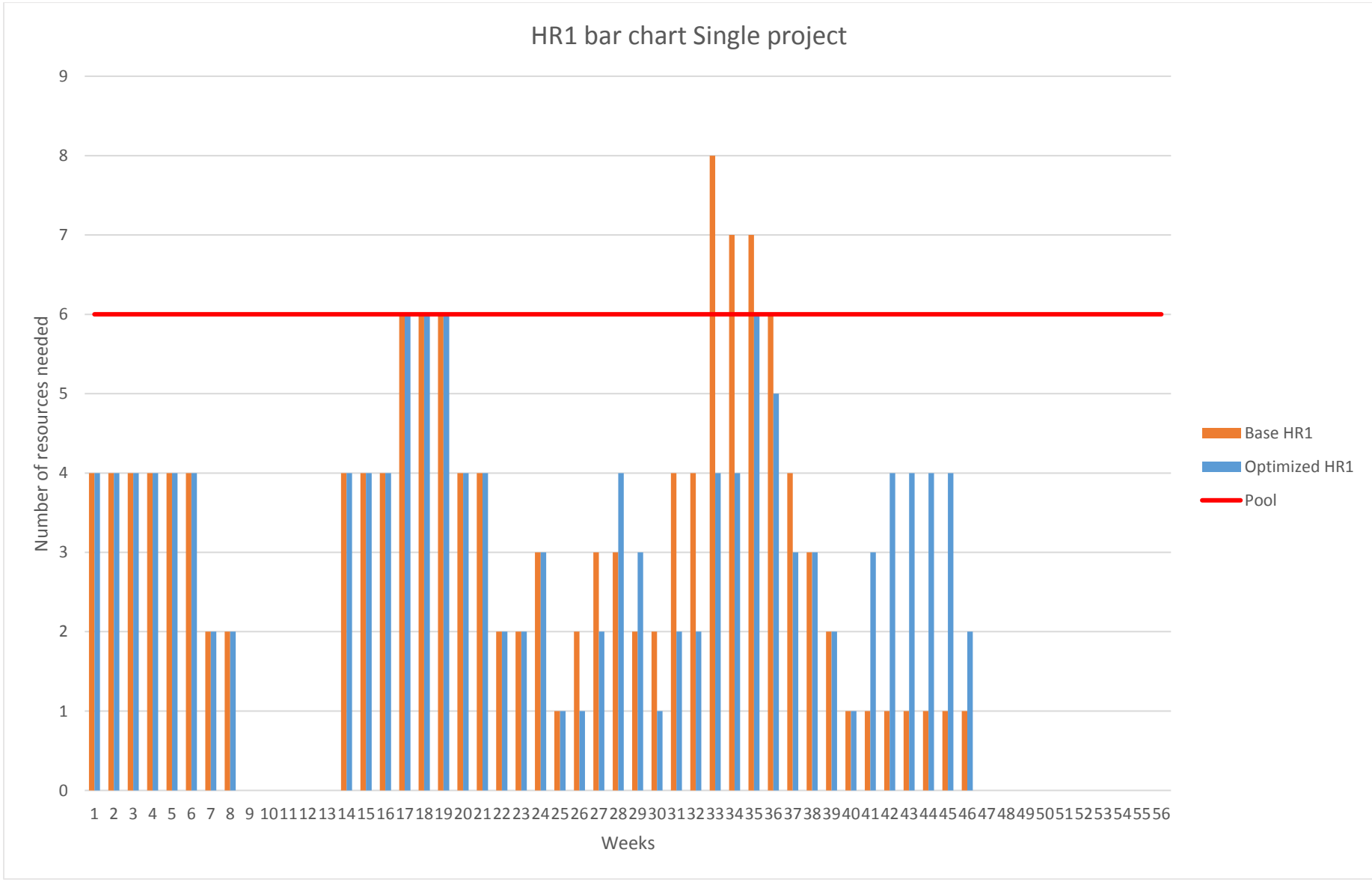


Figure 13 HR1 Bar chart for a single project

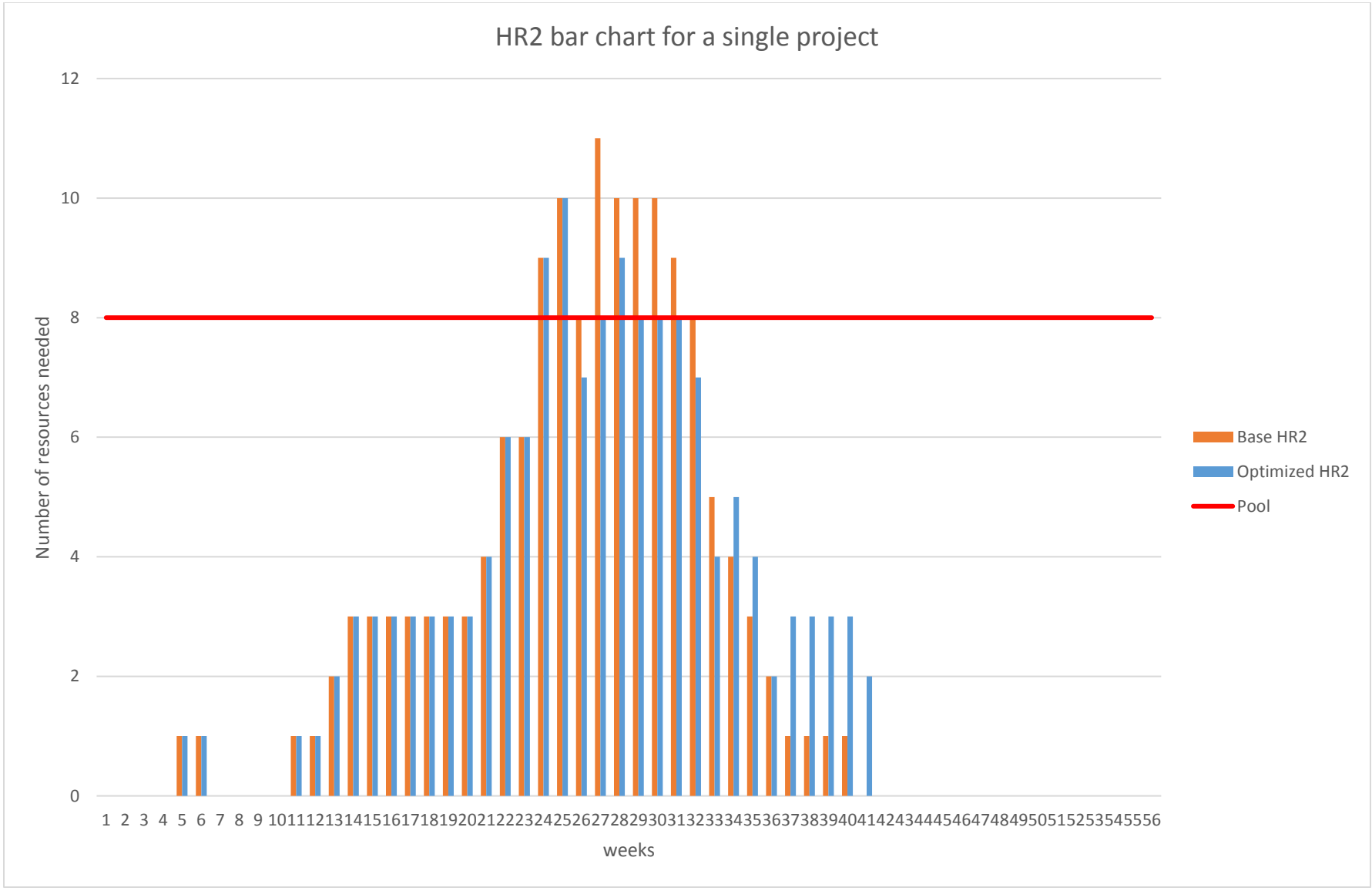


Figure 14 HR2 Bar chart for a single project

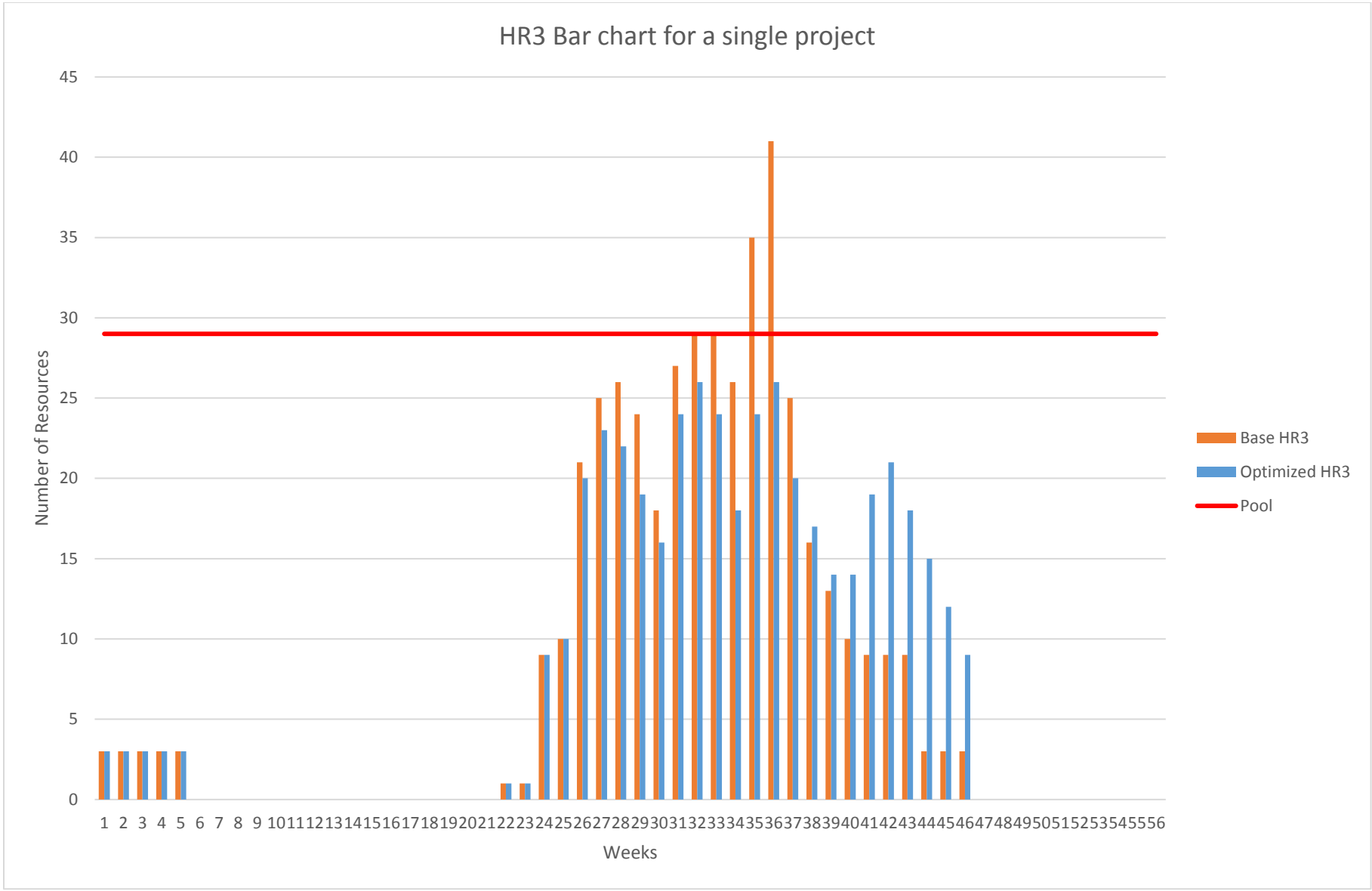


Figure 15 HR3 bar chart for a single project

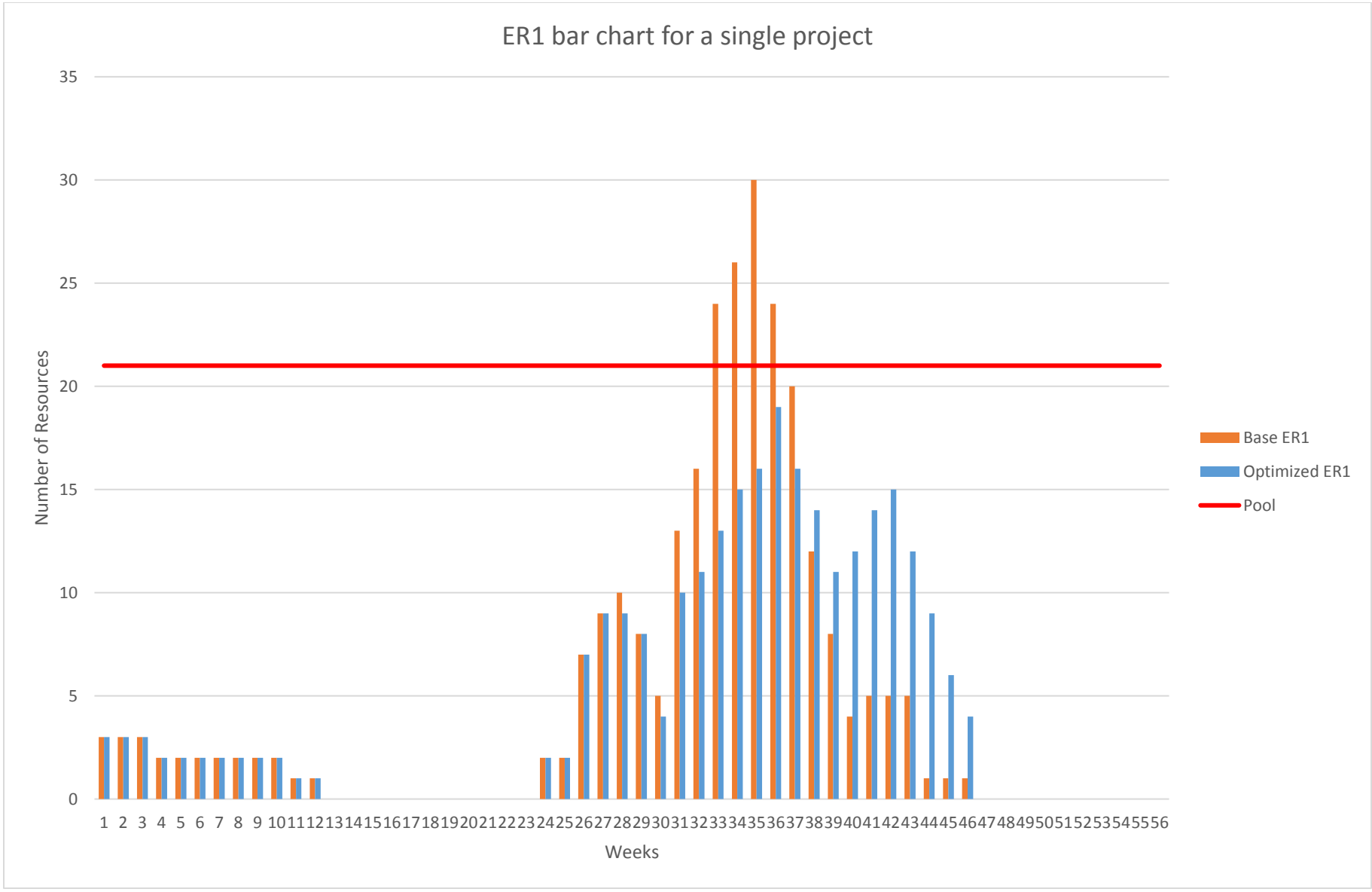


Figure 16 ER1 bar chart for a single project

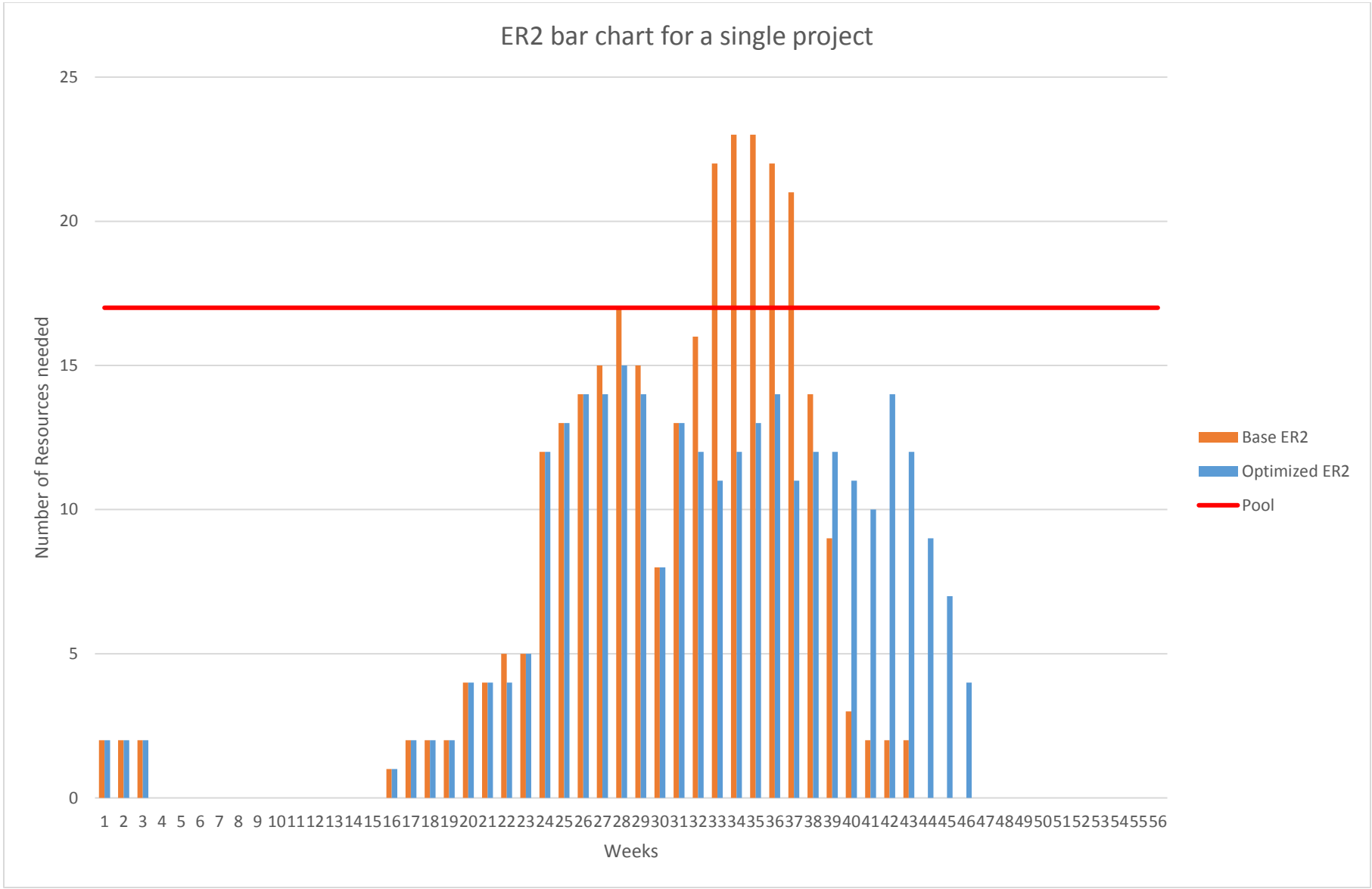


Figure 17 ER2 bar chart for a single project

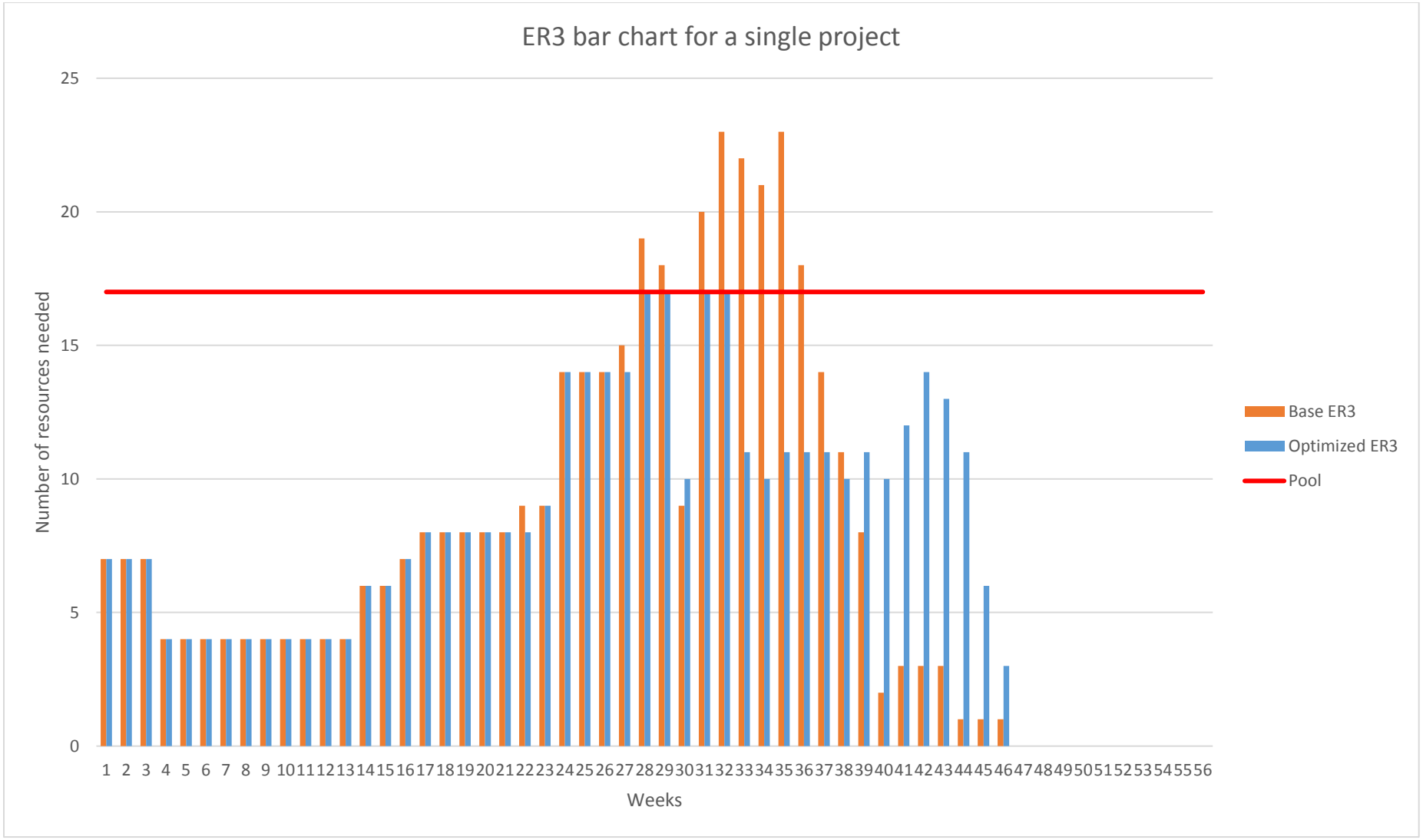


Figure 18 ER3 bar chart for a single project

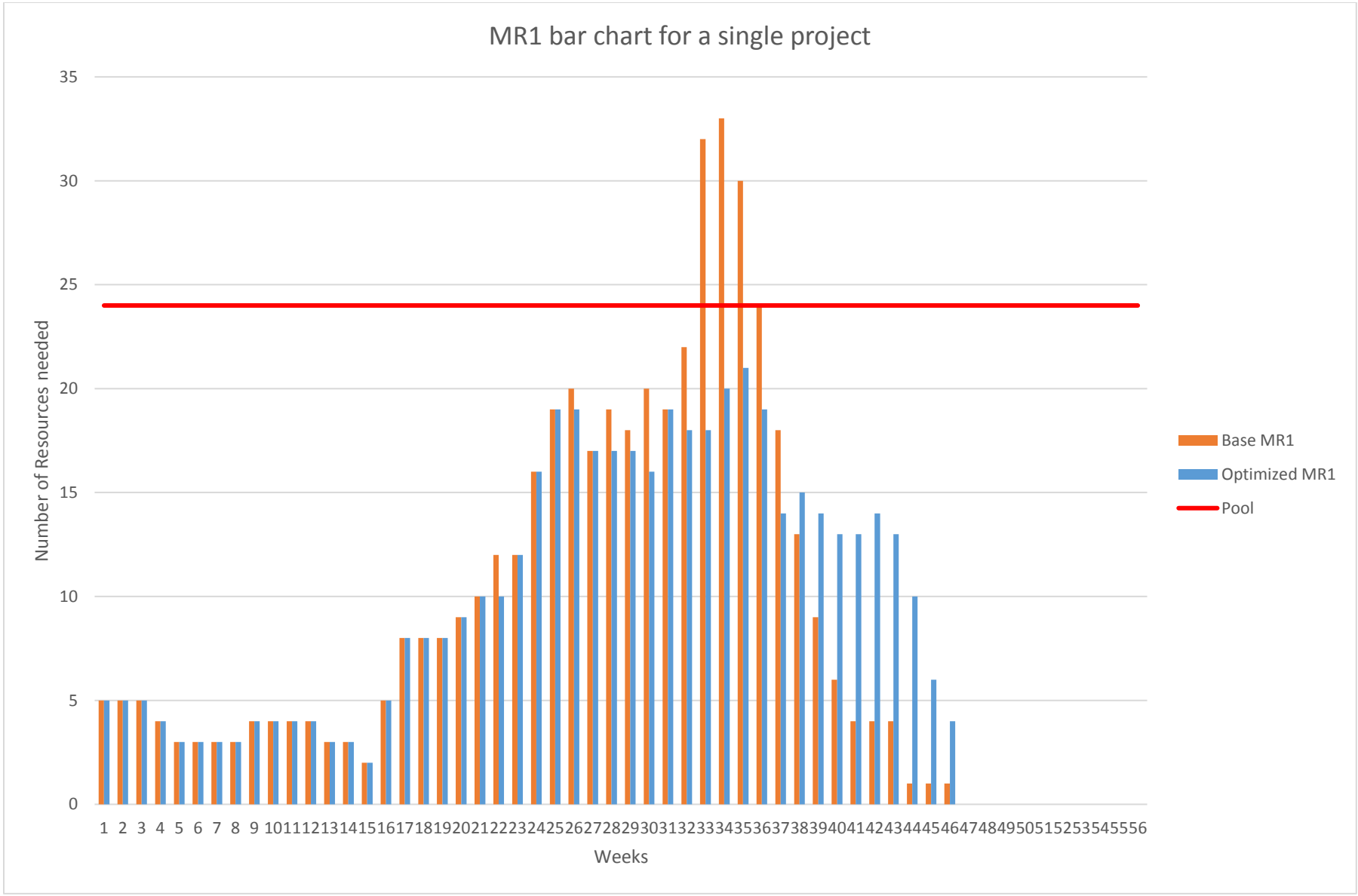


Figure 19 MR1 bar chart for a single project

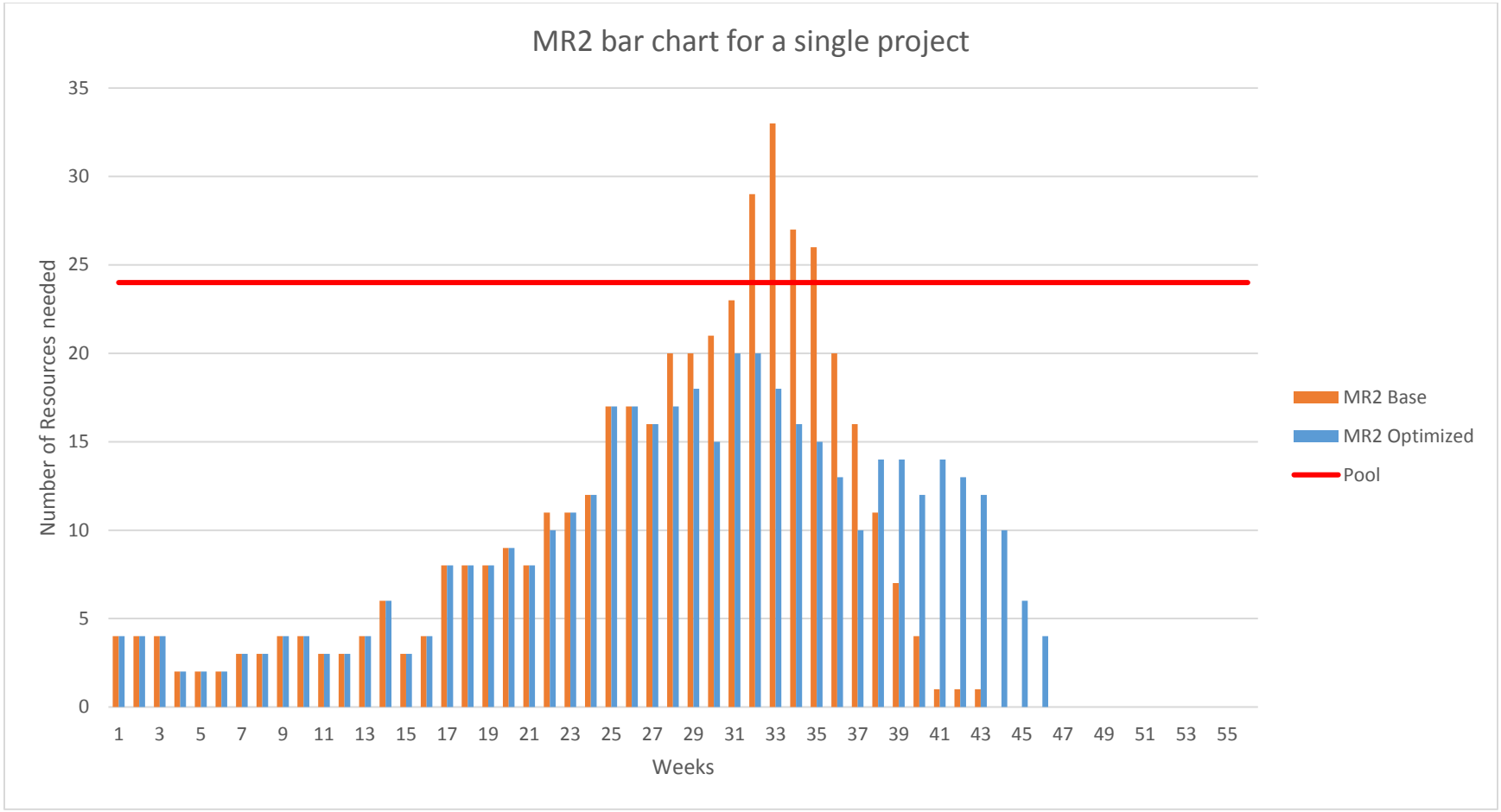


Figure 20 MR2 bar char for a single project

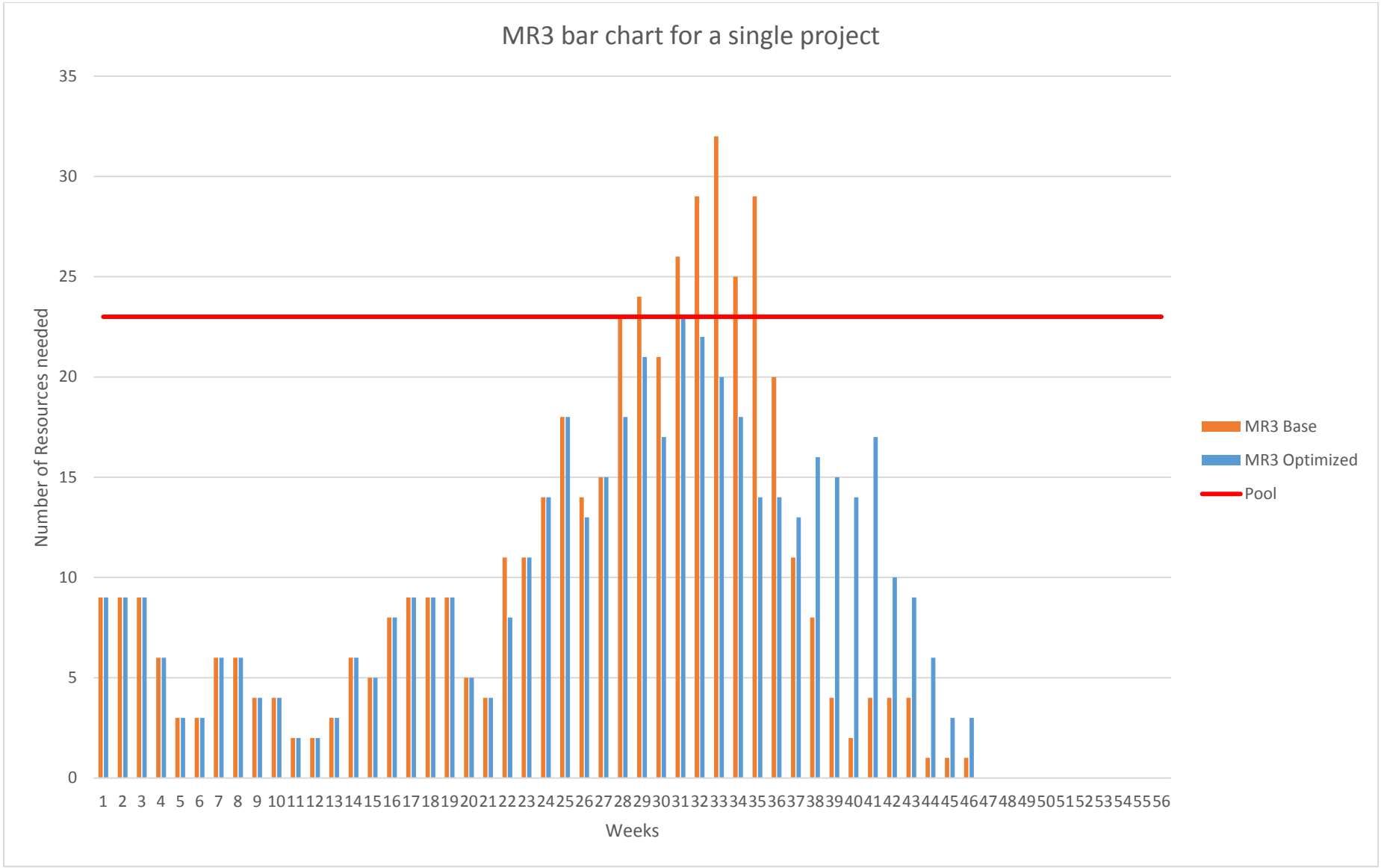


Figure 21 MR3 bar chart for a single project

4.2 Single resource with Multiple Project

The model was tested on a single resource, which was selected to be the resource with the greatest difference in price between pool price and imported price. The resource chosen was MR1. This scenario would happen if there is a shortage in a specific resource, and the project manager wants to reduce the maximum number of that resource needed to meet the available pool.

The extra cost was eliminated after optimization as shown in Figure 22 when we reduced the pool of available resources up to 25%, but when the pool was reduced by 30%, the extra cost was reduced from 248,400 LE to 2,700 LE only which is means it decreased by 99%

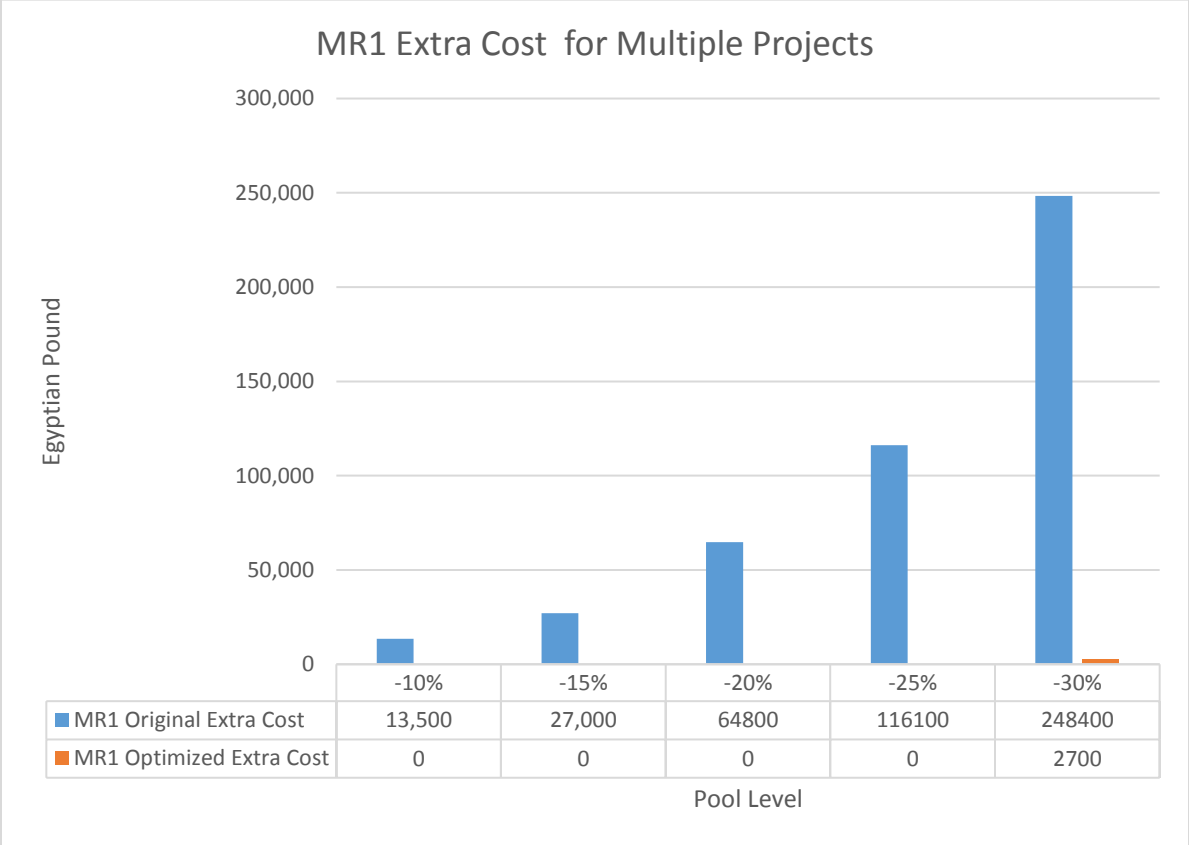


Figure 22 MR1 Extra Cost for Multiple Projects

Figure 23 shows the bar chart of weekly need of resource MR1 before, after optimization and the available pool when reduced by 30% of the maximum need. The model was able to meet the pool limit all through the project's duration except in week#14 where a one extra MR1 was needed.

Figure 24 shows the weekly need of resource MR1 for each project after optimization. From the bar chart, project 2 needed MR1 the most at the beginning, while project 1 needed it the most towards the end as project 2 does not need MR1 anymore after week# 37. From week # 47 till week # 51 only project 3 needed MR1.

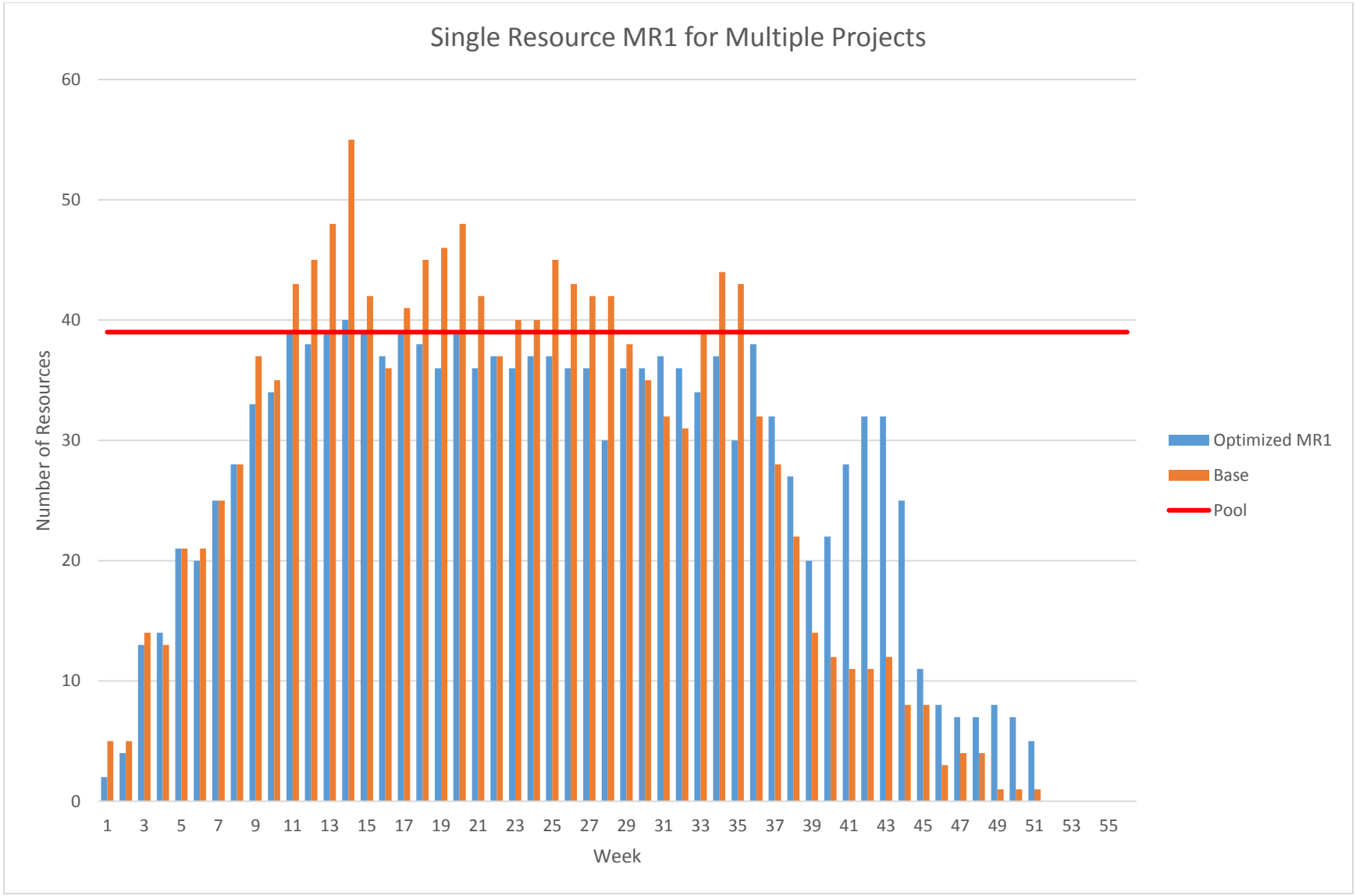


Figure 23 Bar chart for MR1 optimization

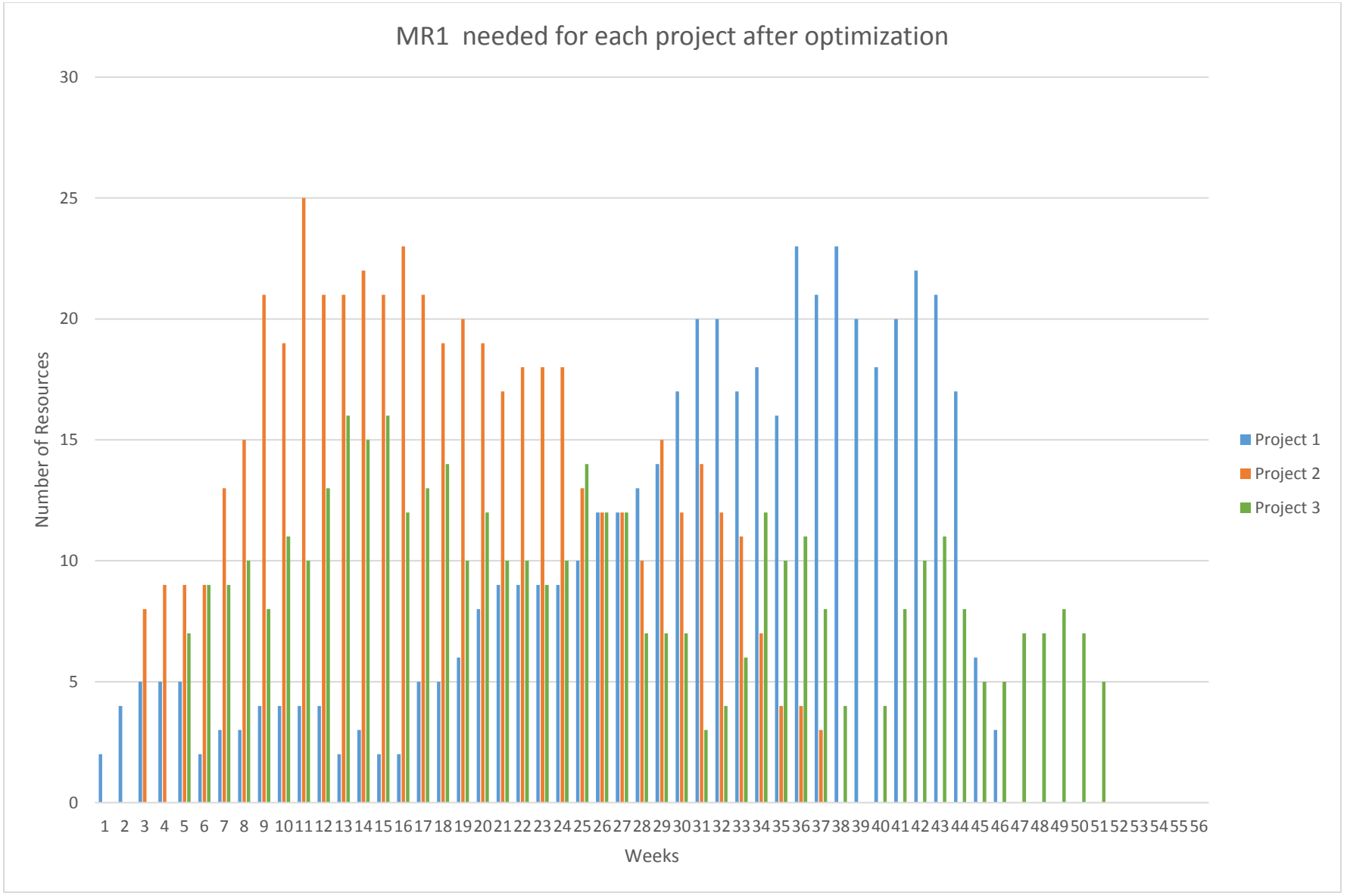


Figure 24 MR1 needed for each project

4.3 Multiple resource with 2 projects

The model was tested to optimize the cost of multiple resources for two projects only. Figure 25 shows reduction in extra cost of resources when reducing the pool of resources by 10%, 15%, 20%, 25% and 30%. Unlike in section 4.1 Multiple resources of Single Project where the model was able to eliminate all the extra cost of resources when reducing the pool of resources up to 30%, in 4.3 Multiple resource with 2 projects the model eliminated the extra cost of resources when the pool was reduced up to 15% only, and then the extra cost of resources couldn't be eliminated anymore. The model decreased the extra cost of resources by:

- 98.3% when the pool was reduced by 20%,
- 89.5% when the pool was reduced by 25%,
- 82.2% when the pool was reduced by 30%.

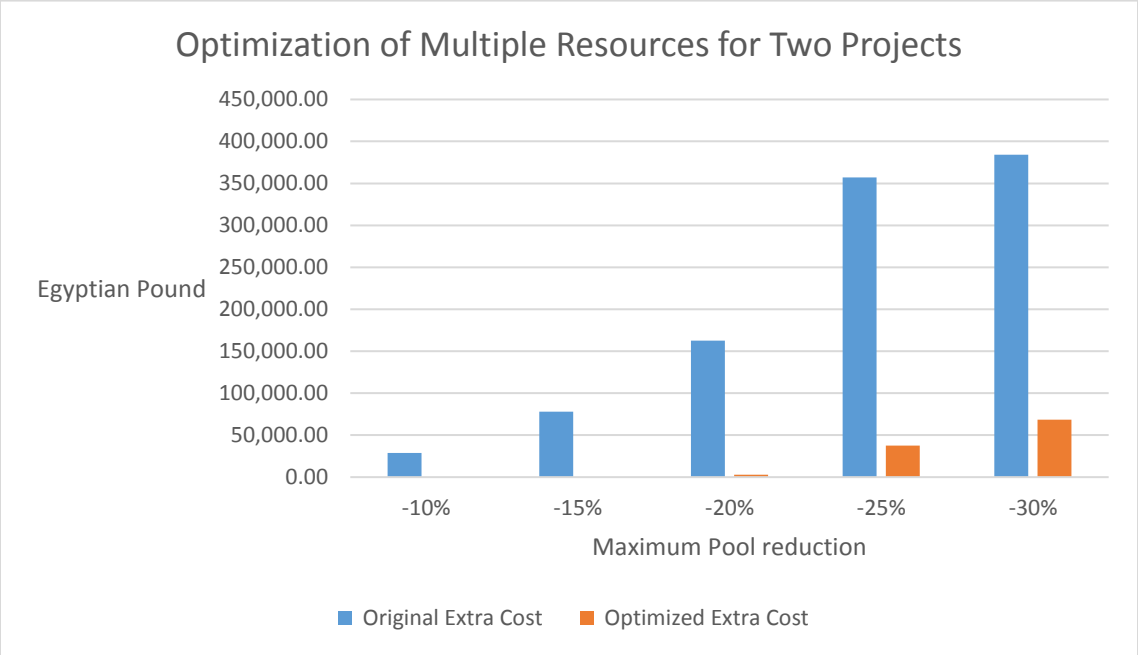


Figure 25 Extra Cost Reduction for multiple resources in two projects

The Schedules of project 1 were generated before and after optimization. Figure 26 shows the schedule before optimization and Figure 27 shows the schedule after optimization. Please note that there was no extension in project's duration and project 1 ended at week # 46 before and after optimization, but few activities were shifted towards the end of the project and became critical activities which lead to increasing the criticality ration of the project.

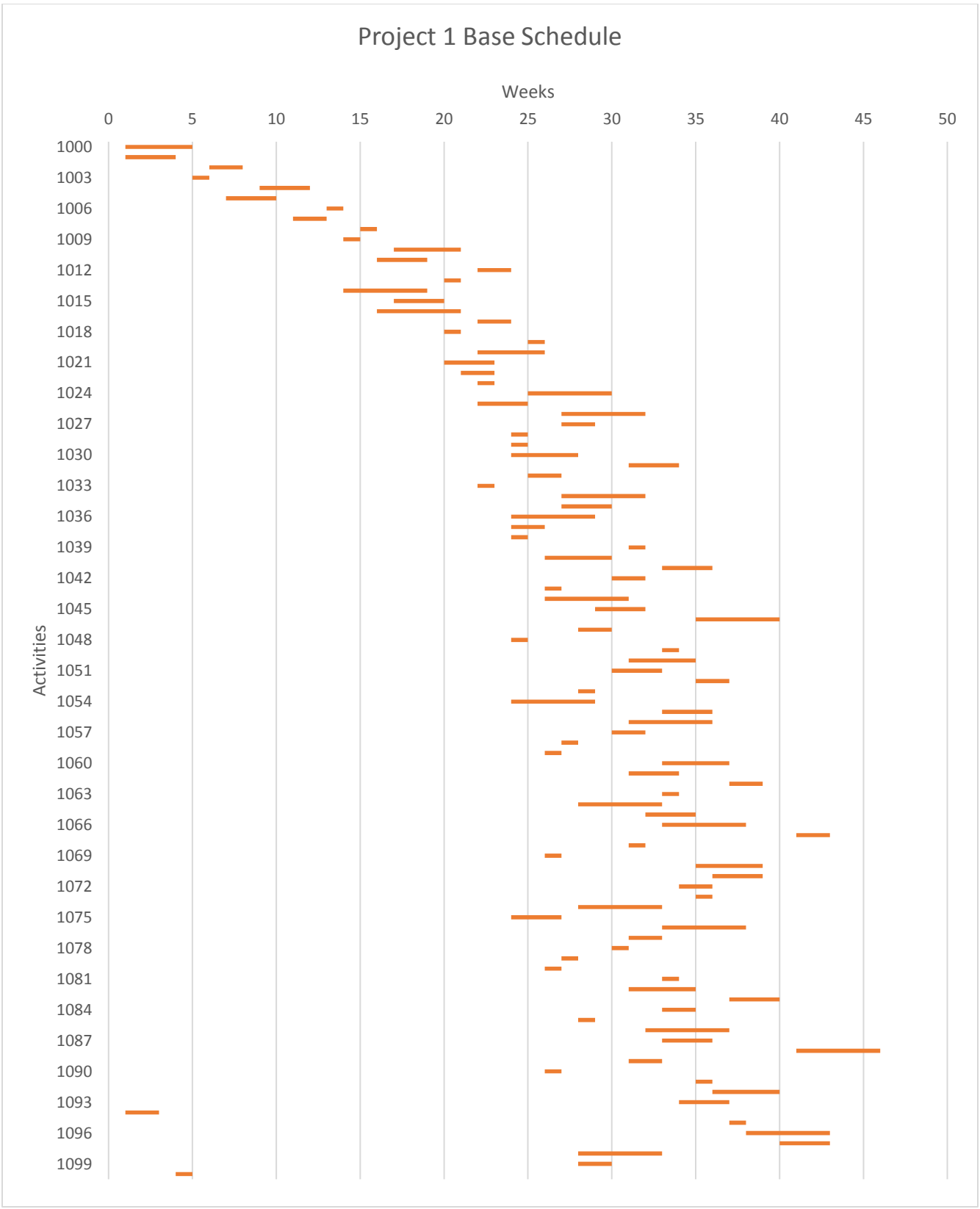


Figure 26 Project 1 Base Schedule

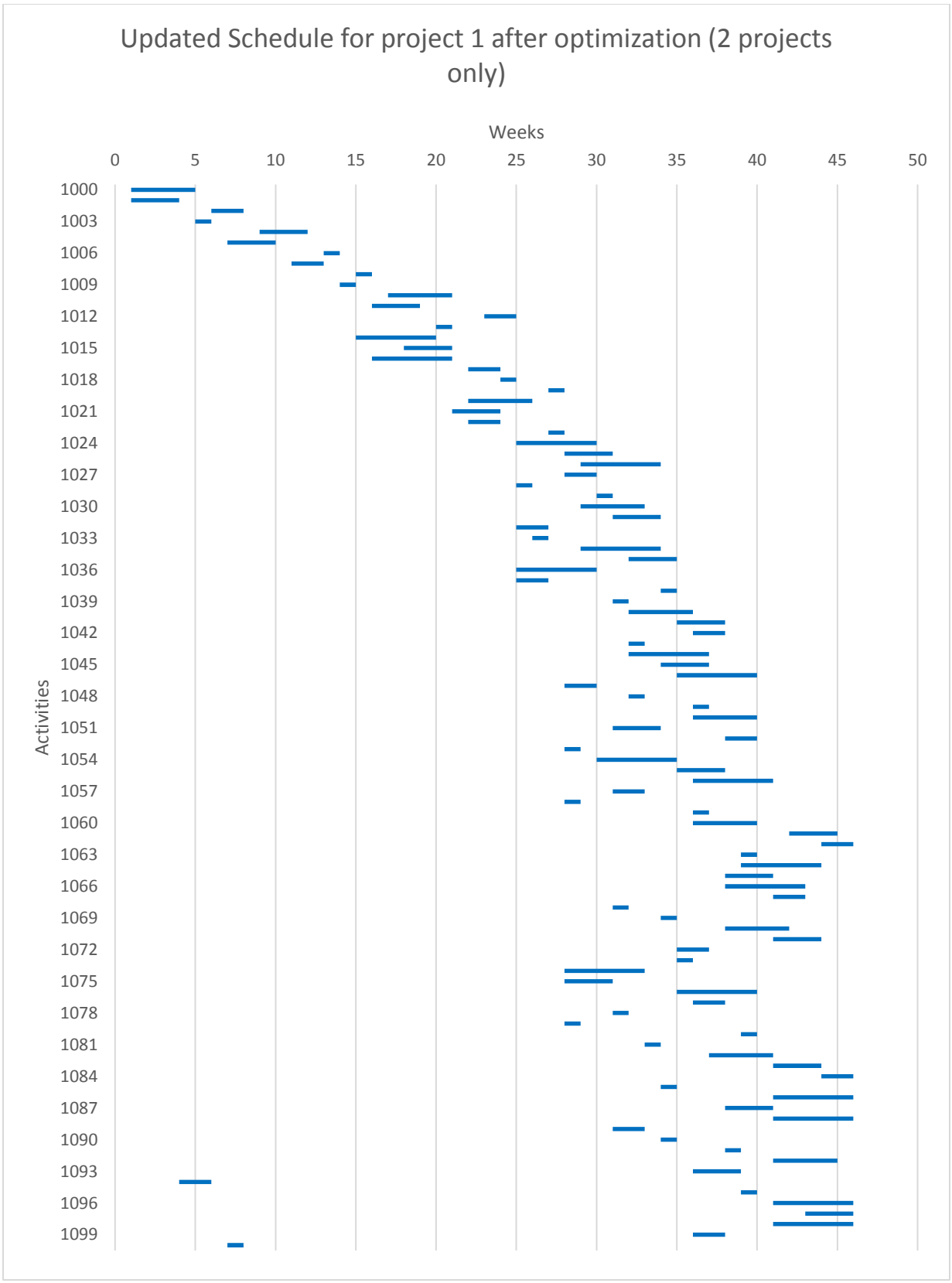


Figure 27 Updated schedule for project 1 after optimization of resources of two projects

Project 2 base schedule is shown in Figure 28 and the after optimization updated schedule is shown in Figure 29. Project 2 schedule started in week#3 and ended in week#37 before and after optimization, but few activities were shifted within their available float towards the end of the project and increased the criticality ratio of the project.

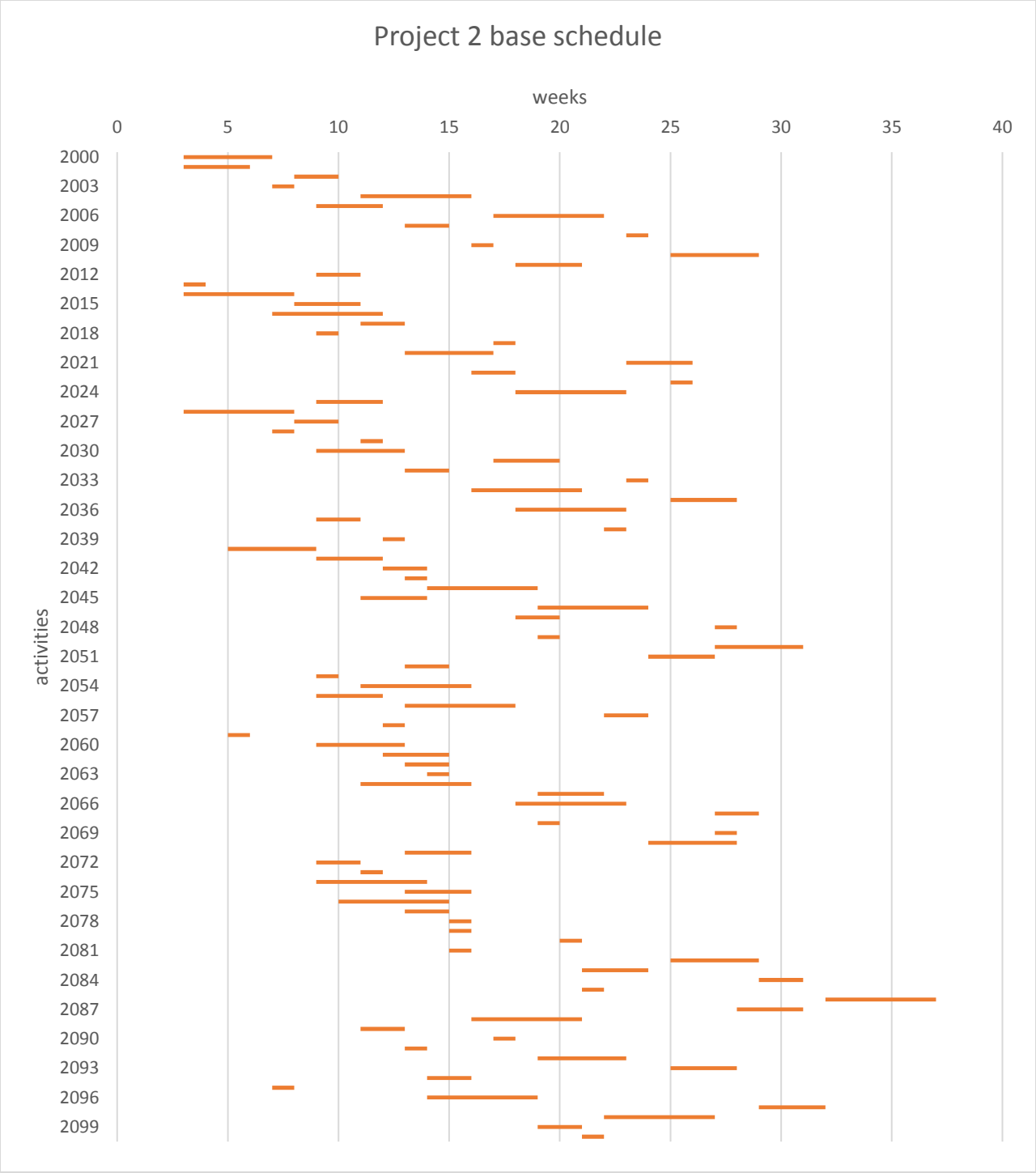


Figure 28 Base schedule of project 2

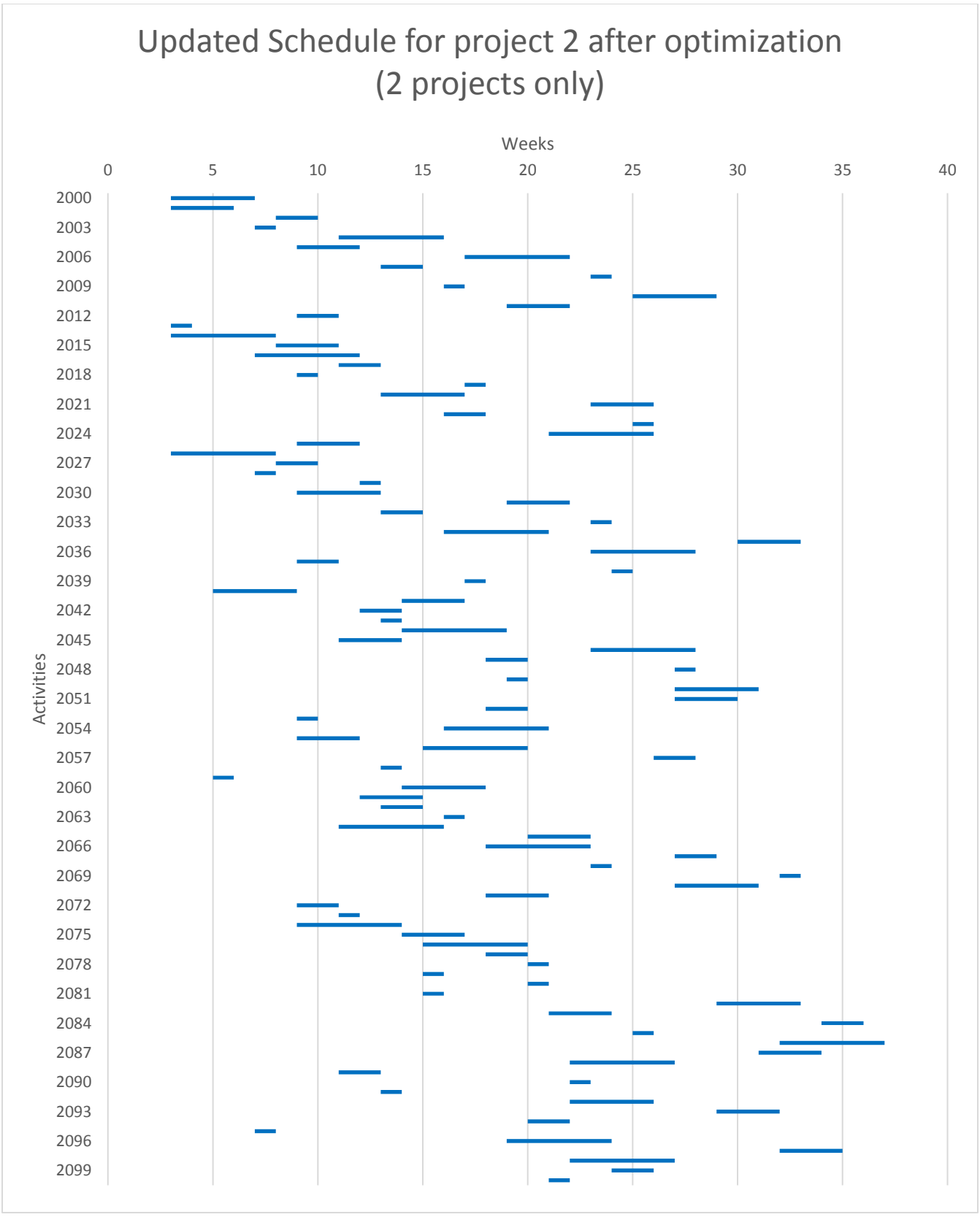


Figure 29 Updated schedule for project 2 after optimization (2 projects only)

Figure 30-Figure 38 are bar charts showing the number of resources needed each week before optimization (base) and after optimization. The pool of each resource is 30% less than the maximum resource needed before optimization. Each resource has its own bar chart and the allocating of the resources are shown afterwards.

Figure 30 shows that the maximum number of HR1 needed after optimization is reduced from 15 HR1 to 13 HR1, while the pool available was 11. Also, the total number of extra HR1 was reduced more than 50% after optimization which lead to decreasing the cost of extra resources needed.

Figure 31 shows that the maximum number of HR2 needed after optimization is reduced from 27 HR2 to 22 HR2, while the pool was 19. Also, the total number of extra HR2 was reduced after optimization which lead to decreasing the cost of extra resources needed.

Figure 32 shows that the maximum number of HR3 needed after optimization is reduced from 31 HR3 to 26 HR3, while the pool was 22. Also, the total number of extra HR3 was reduced after optimization by more than 70% which lead to decreasing the cost of extra resources needed.

Figure 33 shows that the maximum number of ER1 needed after optimization is reduced from 32 ER1 to 26 ER1, while the pool is 23. Also, the total number of extra ER1 was reduced after optimization by more than 70% which lead to decreasing the cost of extra resources needed.

Figure 34 shows that the maximum number of ER2 needed after optimization is reduced from 27 Er2 to 22 ER2, while the pool is 19. Also, the total number of extra ER2 was reduced after optimization by more than 85% which lead to decreasing the cost of extra resources needed.

Figure 35 shows that the maximum number of ER3 needed after optimization is reduced from 33 ER3 to 25 ER3, while the pool is 24. Also, the total number of extra ER3 was reduced after optimization by more than 95% which lead to decreasing the cost of extra resources needed.

Figure 36 shows that the maximum number of MR1 needed after optimization is reduced from 37 MR1 to 26 MR1, while the pool is 26. Also, the total number of extra MR1 was reduced after optimization by more than 70% which lead to decreasing the cost of extra resources needed.

Figure 37 shows that the maximum number of MR2 needed after optimization is reduced from 36 MR2 to 26 MR2, while the pool is 26. Also, the total number of extra MR2 was reduced after optimization by more than 90% which lead to decreasing the cost of extra resources needed.

Figure 38 shows that the maximum number of MR3 needed after optimization is reduced from 39 MR3 to 26 MR3, while the pool is 28. Also, the total number of extra MR3 was reduced after optimization by more than 80% which lead to decreasing the cost of extra resources needed.

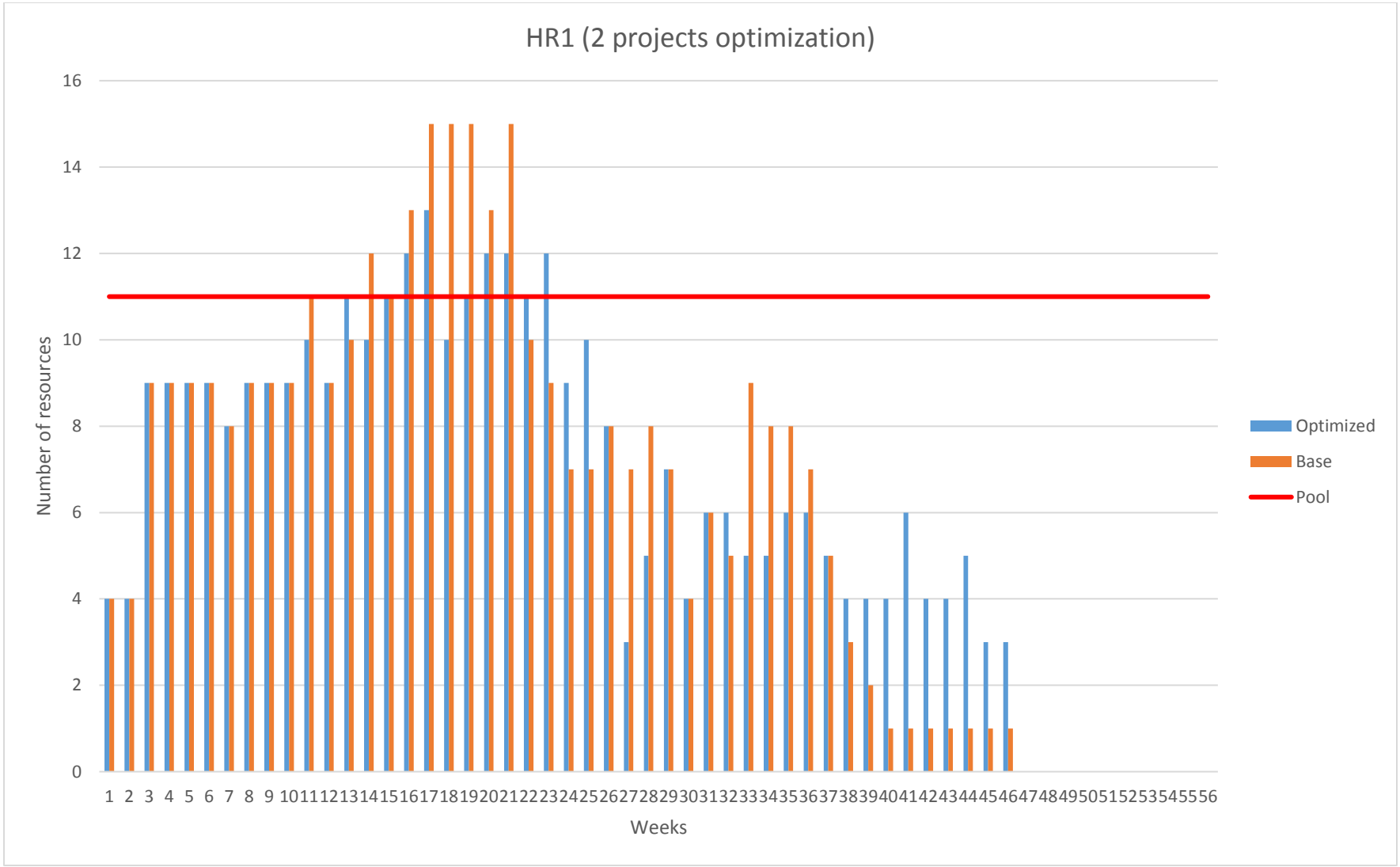


Figure 30 HR1 bar chart (2 projects optimization)

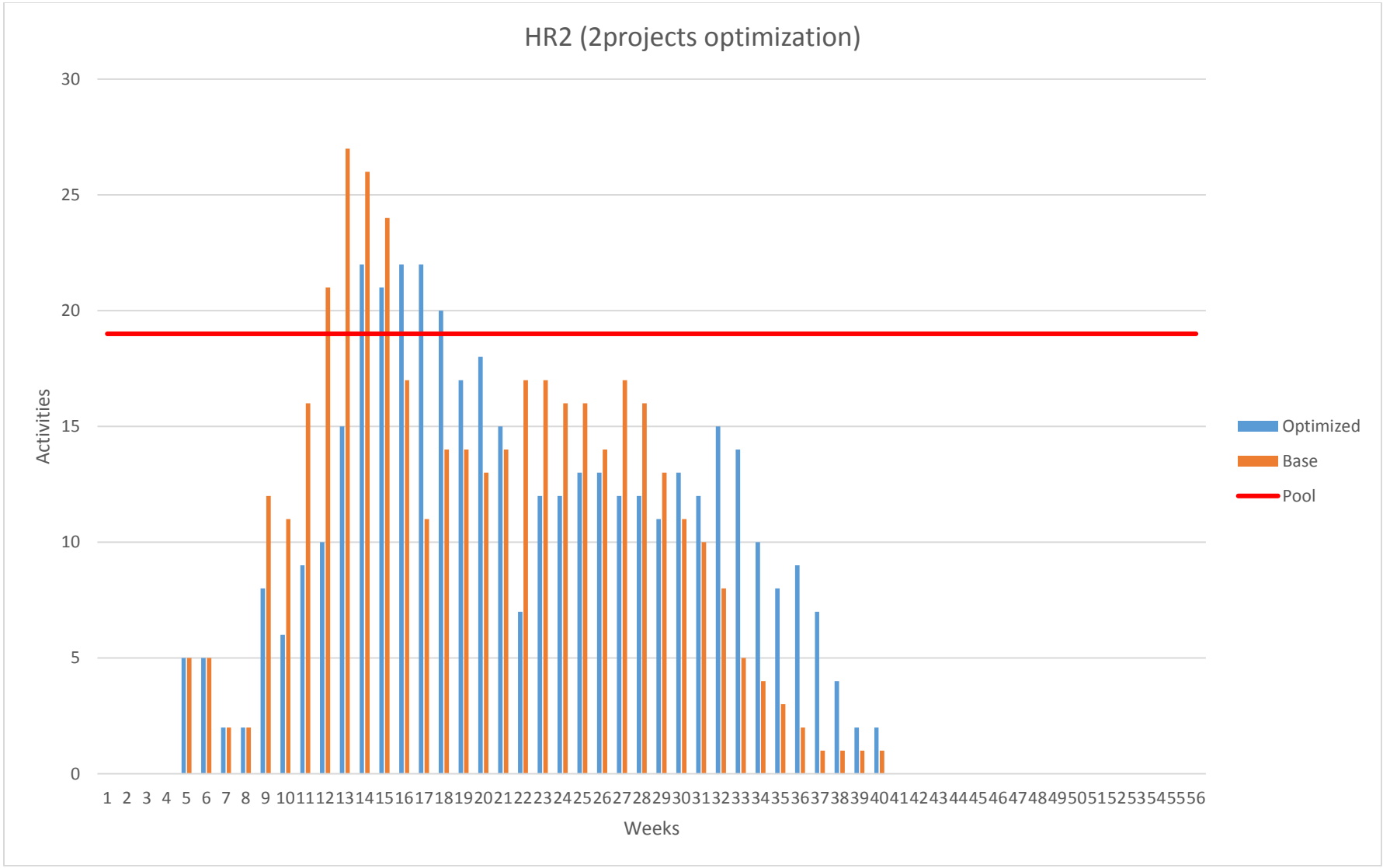


Figure 31 HR2 bar chart (2projects optimization)

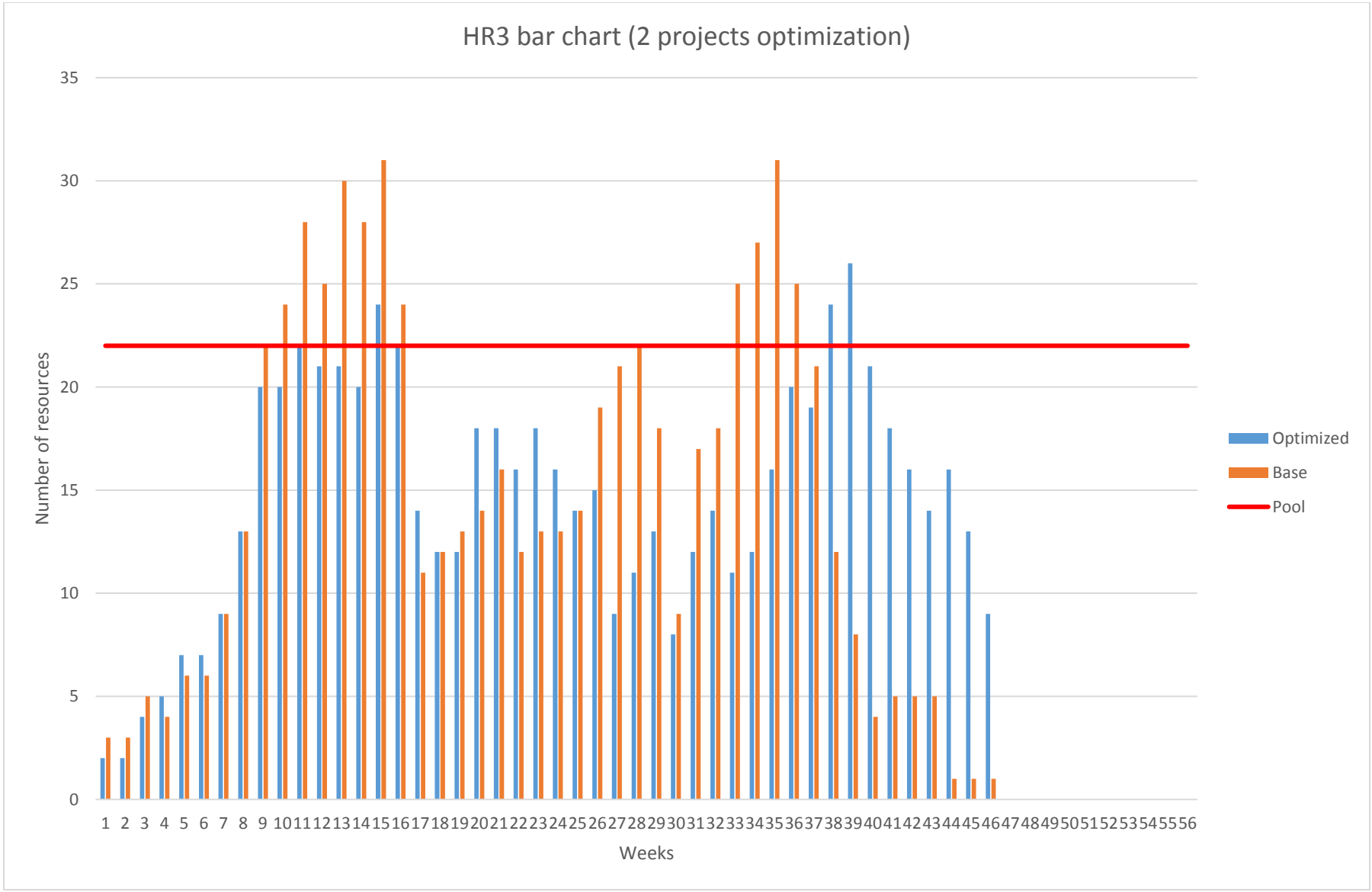


Figure 32 HR3 bar chart (2 projects optimization)

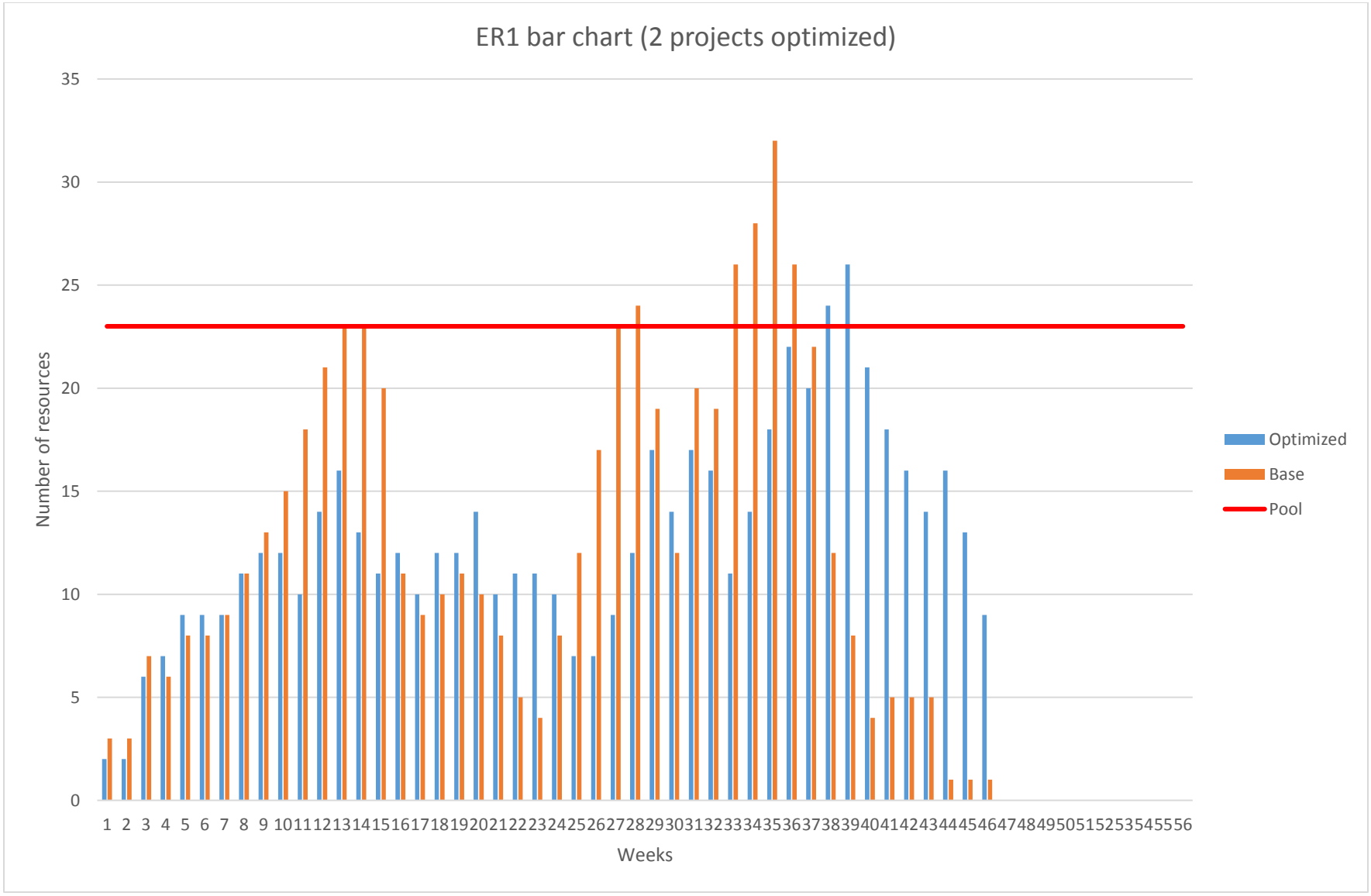


Figure 33 ER1 bar chart (2 projects optimized)

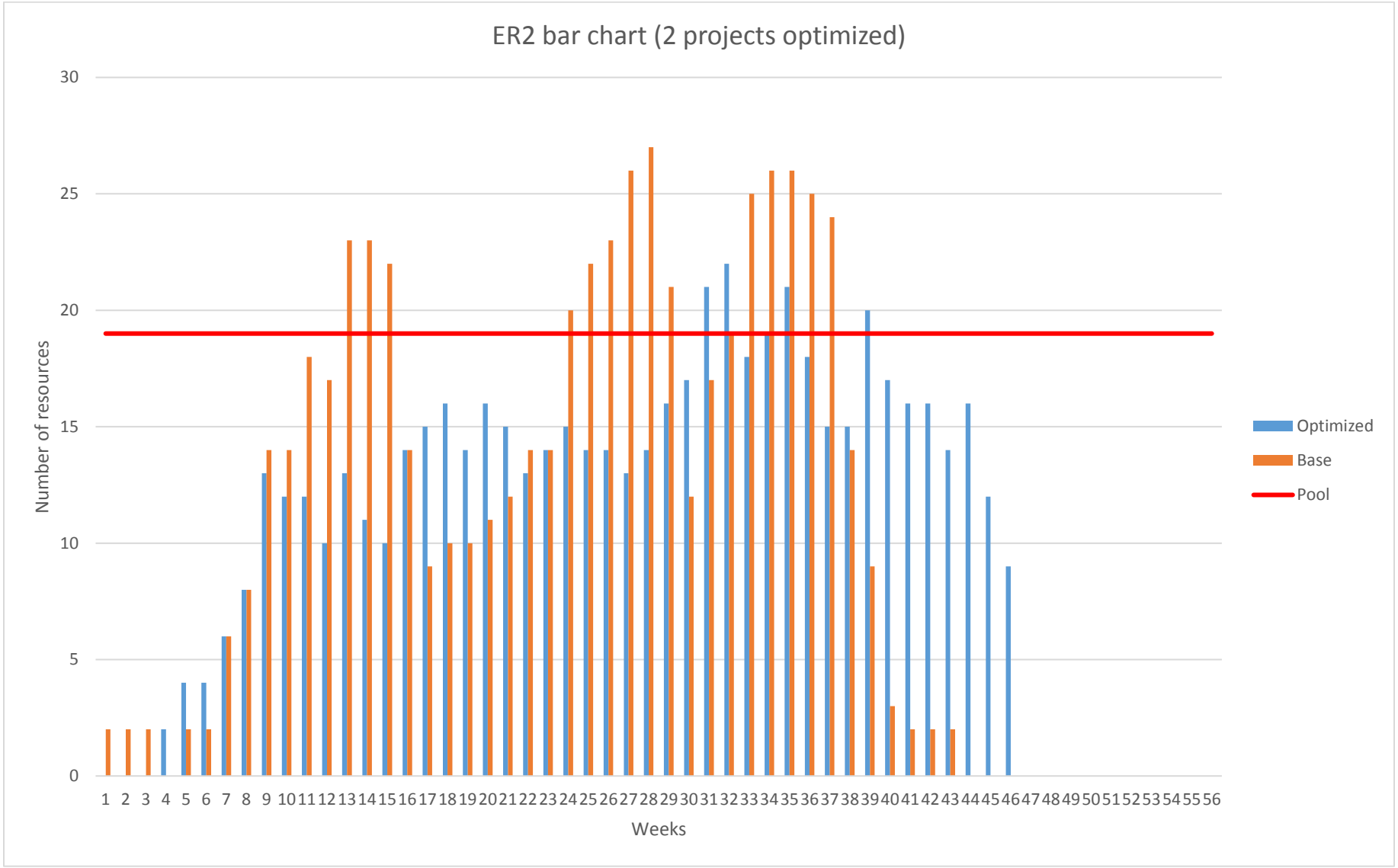


Figure 34 ER2 bar chart (2 projects optimized)

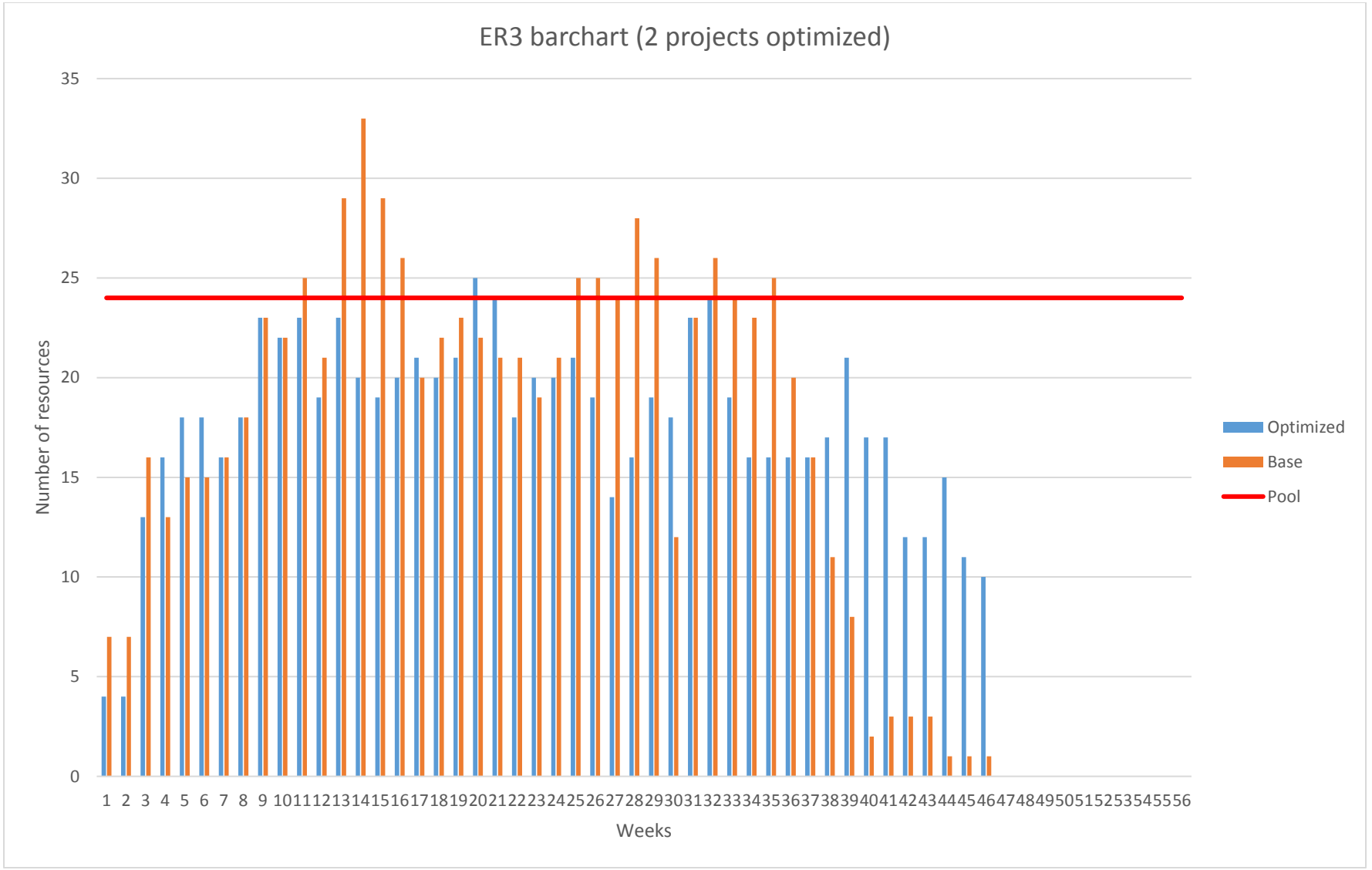


Figure 35 ER3 bar chart (2 projects optimized)

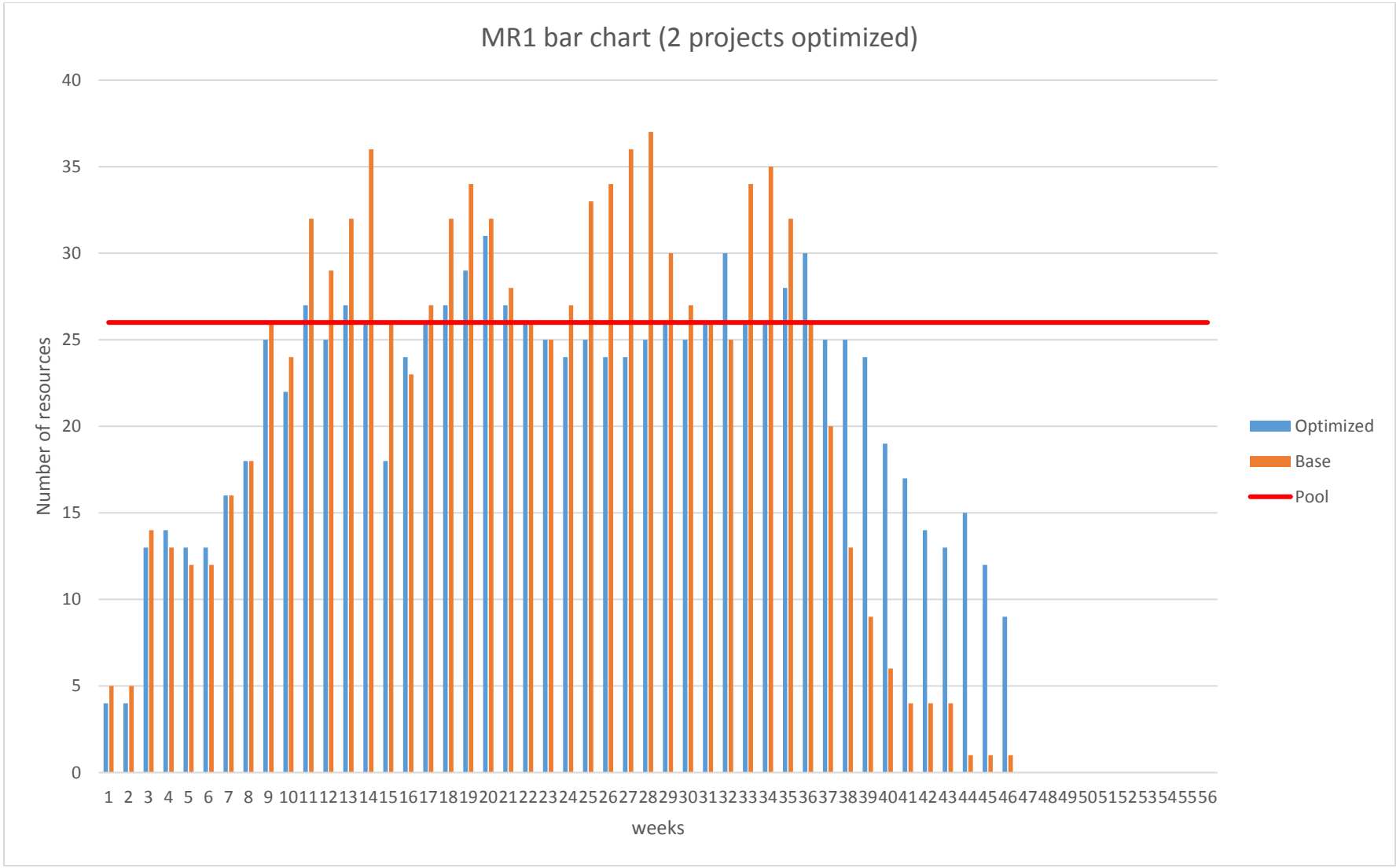


Figure 36 MR2 bar chart (2 projects optimized)

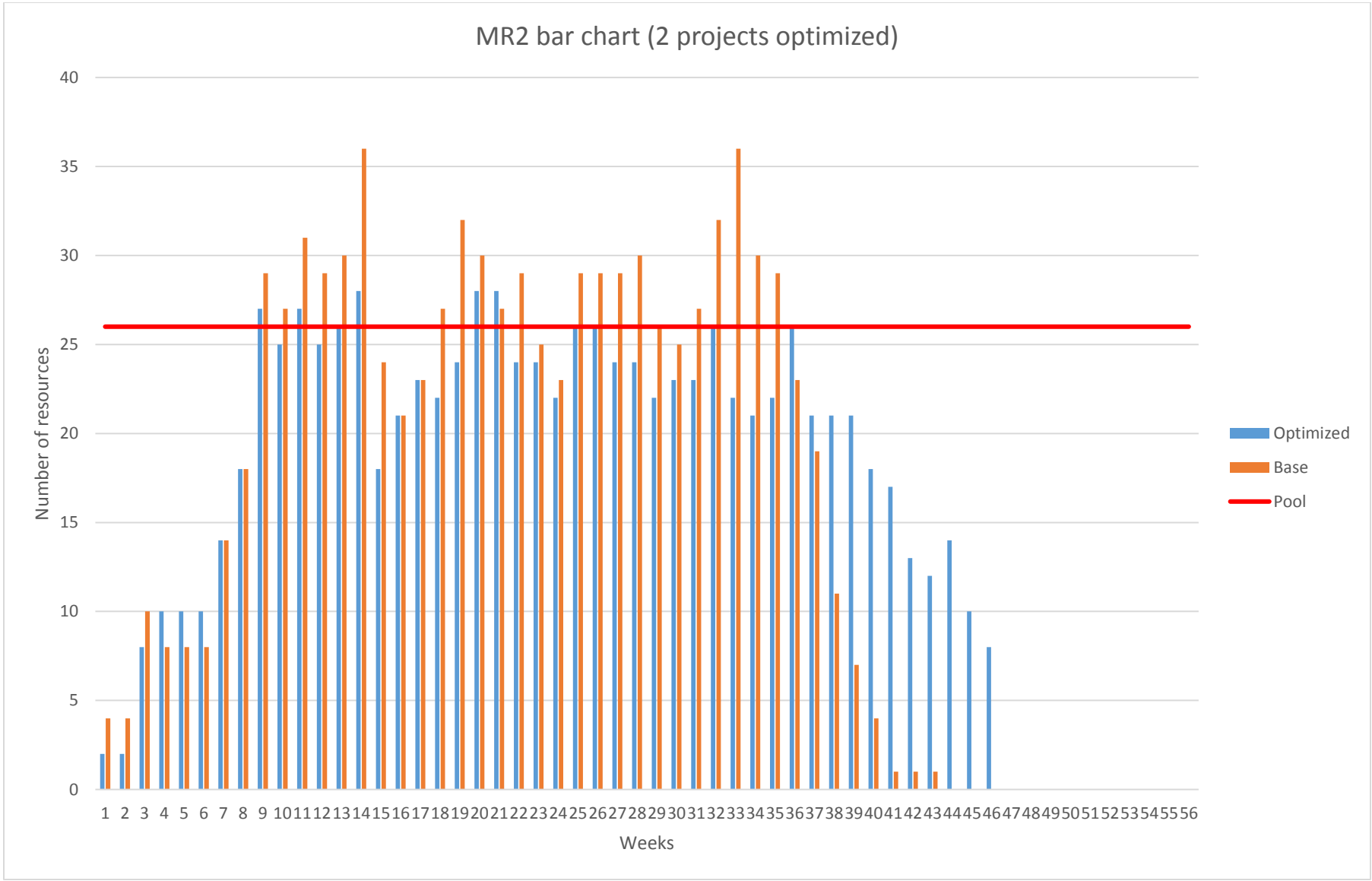


Figure 37 MR2 bar chart (2 projects optimized)

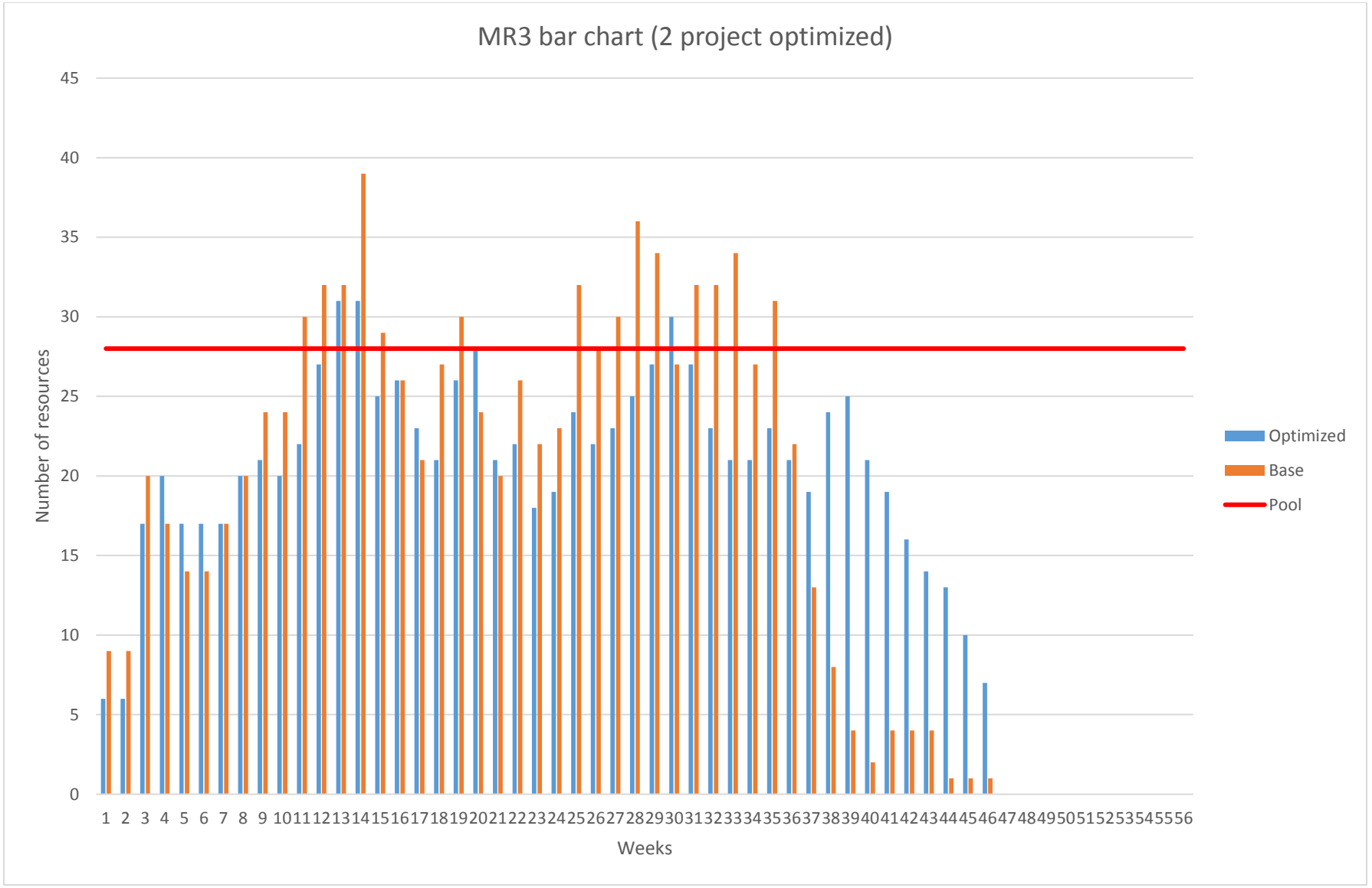


Figure 38 MR3 bar chart (2 projects optimized)

4.4 Multiple resource of 3 projects meeting deadlines

The model was tested on three projects sharing nine resources.

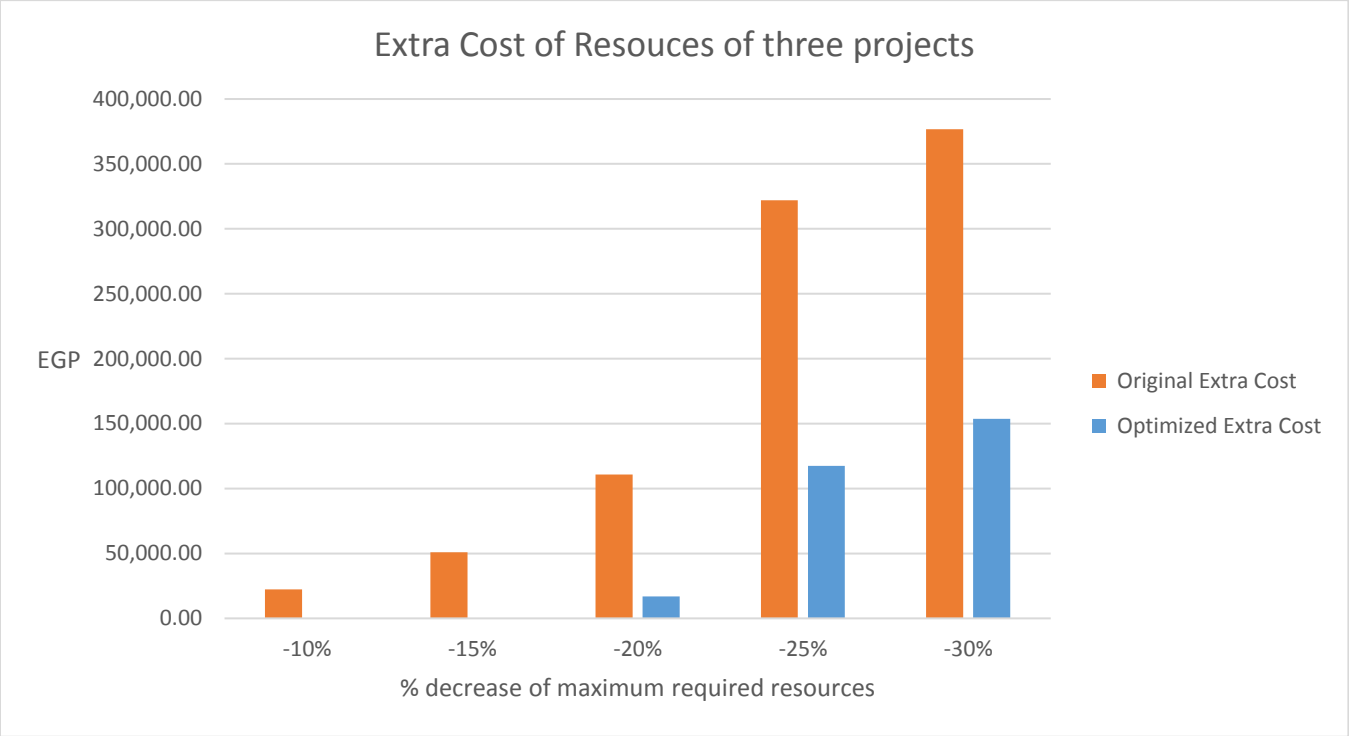


Figure 39 Extra cost of resources of three projects

Figure 39 shows that when the pool of available resources was reduced by 10% and 15%, the cost of extra resources was almost eliminated after optimization. When the pool was reduced by 20%, the extra cost of resources was decreased by 85% after optimization. But when the pool was reduced by 25% and 30%, the decrease in extra cost of resources was more than 65% and 60% respectively.

Figure 40-Figure 42 shows the base schedules of projects 1-3 respectively, and Figure 43-Figure 45 shows the updated schedules after optimization of projects 1-3 respectively with pool of resources decreased by 30%. Please note that the schedules of each project differs with each optimization trial, because there is no optimum solution or optimum schedule in GA. All these outcomes are near-optimum. But most importantly to note in Table 1 that all projects'

schedules started after optimization on the same day as before optimization and finished on the same day as before optimization, but the start date and end date of each activity within the project may differ.

Table 6 Start and End Weeks of the three projects before and after optimization

	Before Optimization		After Optimization	
	Start Week	End Week	Start Week	End Week
Project 1	1	46	1	46
Project 2	3	37	3	37
Project 3	5	51	5	51

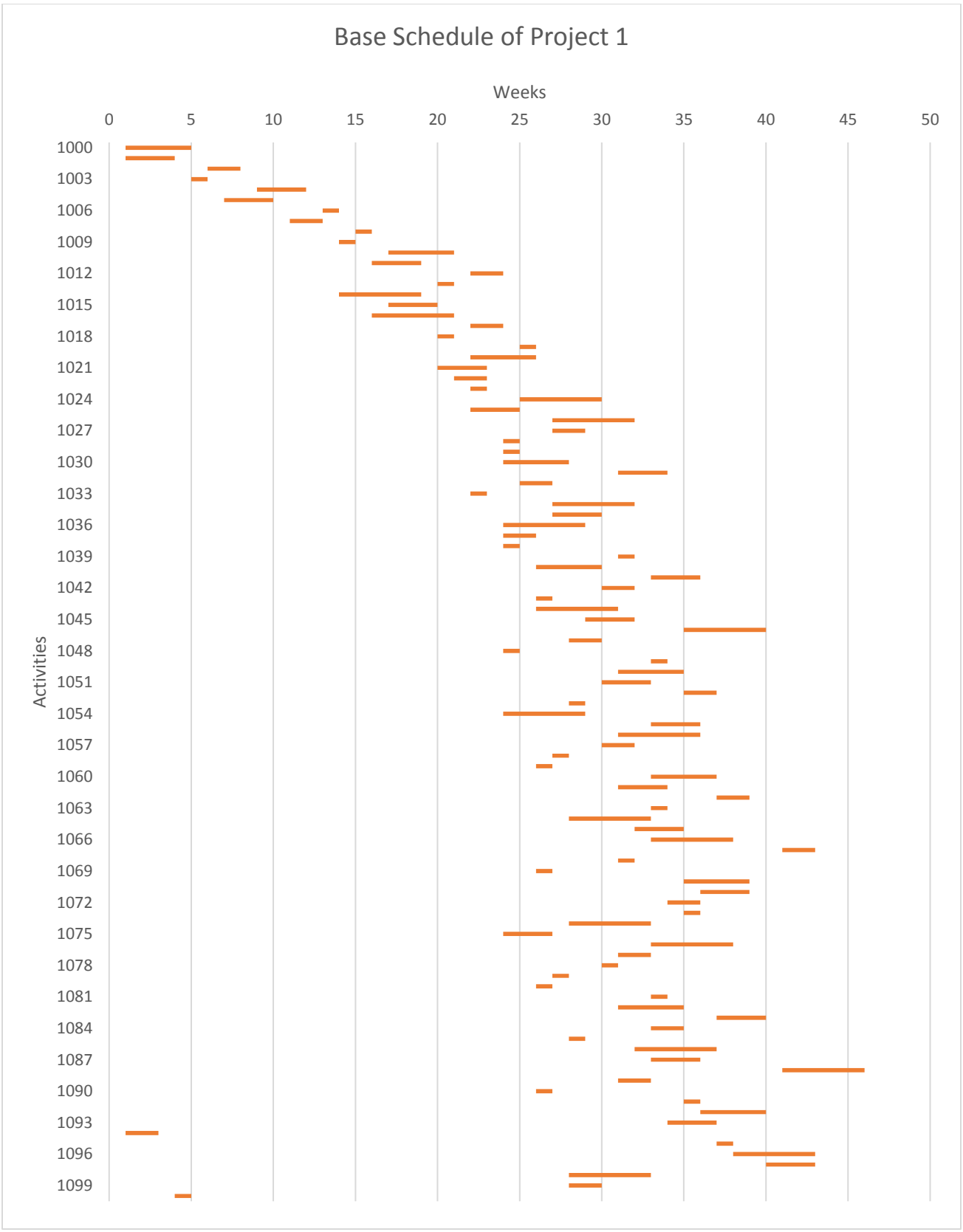


Figure 40 Base Schedule of Project 1

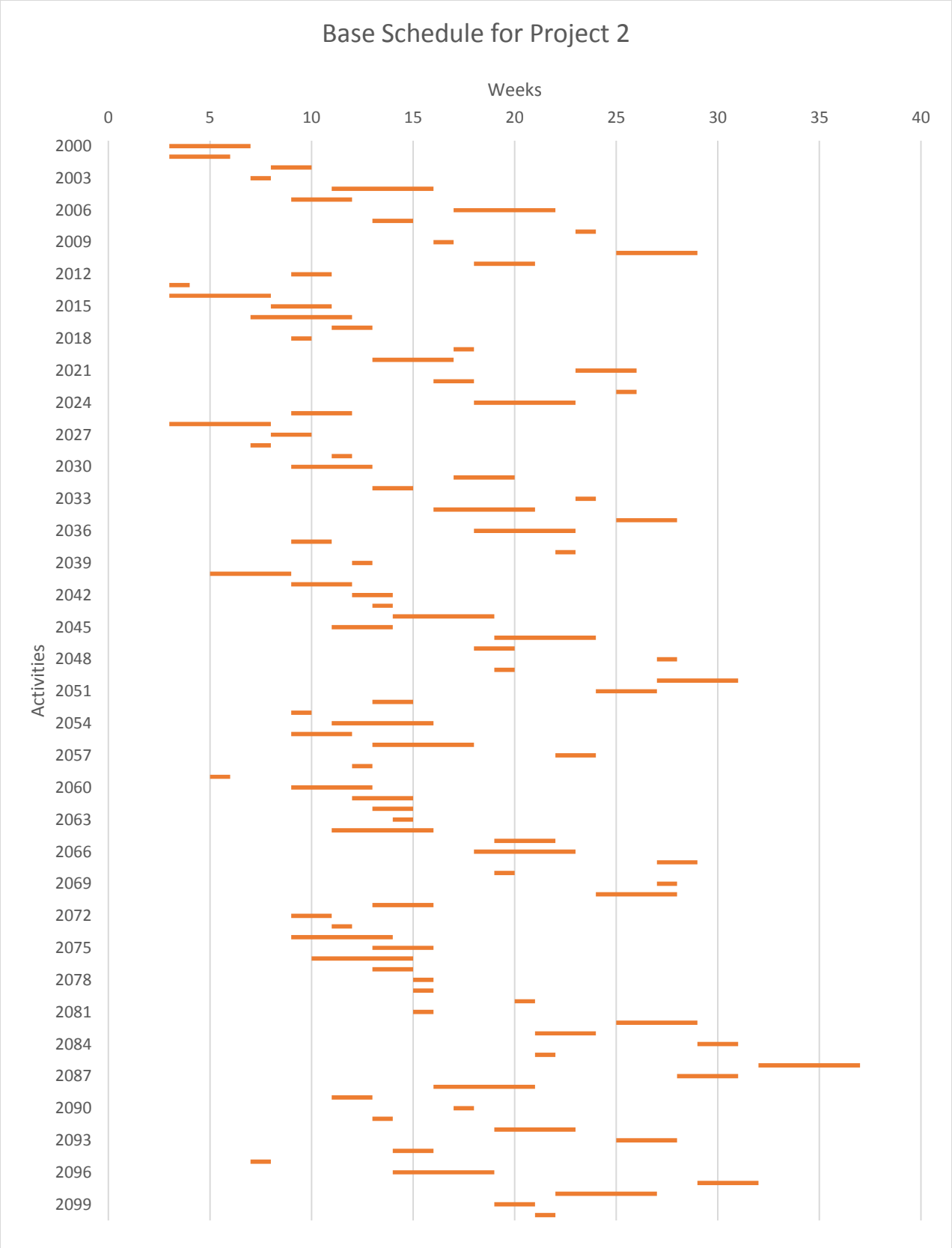


Figure 41 Base Schedule for Project 2

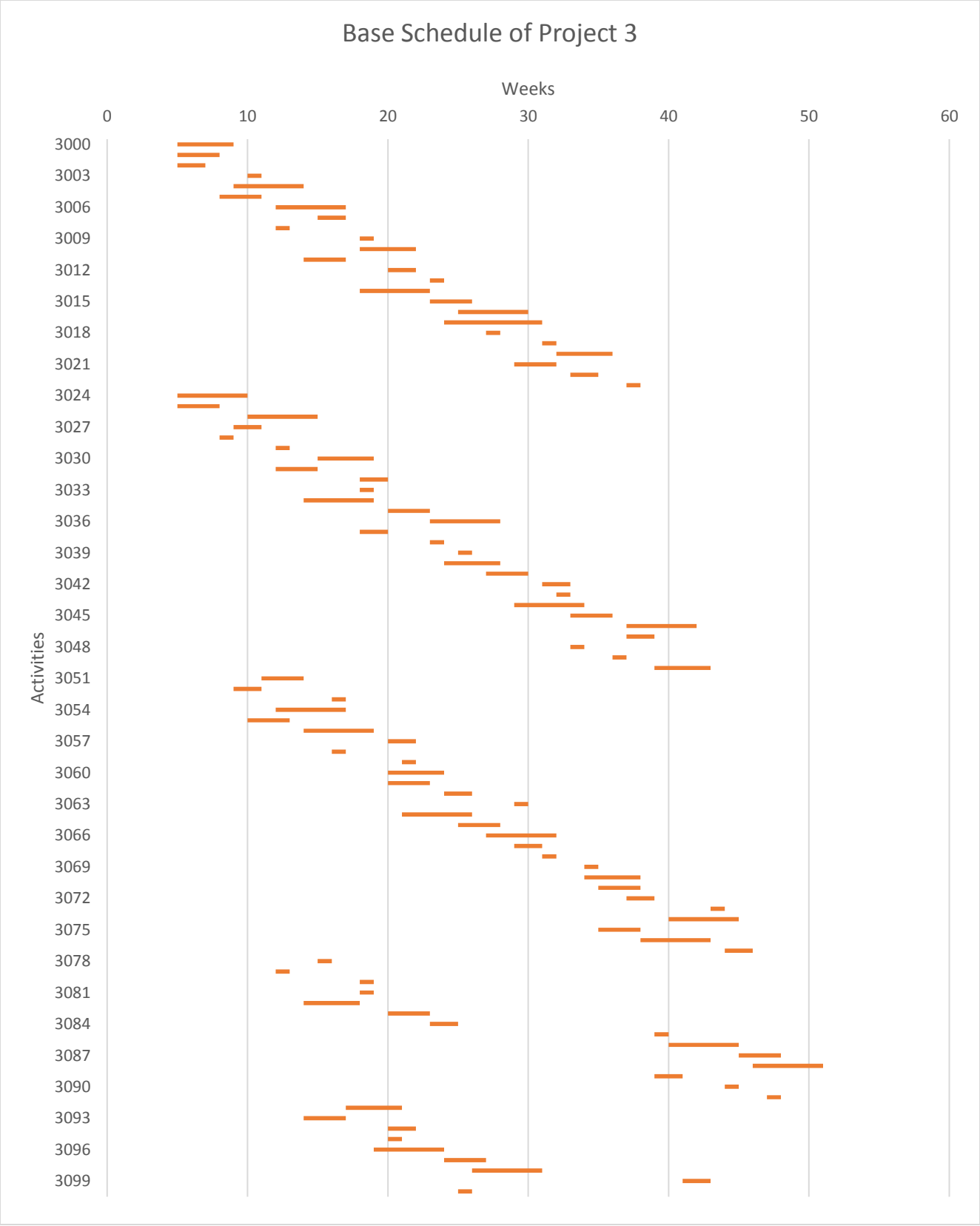


Figure 42 Base Schedule for Project 3

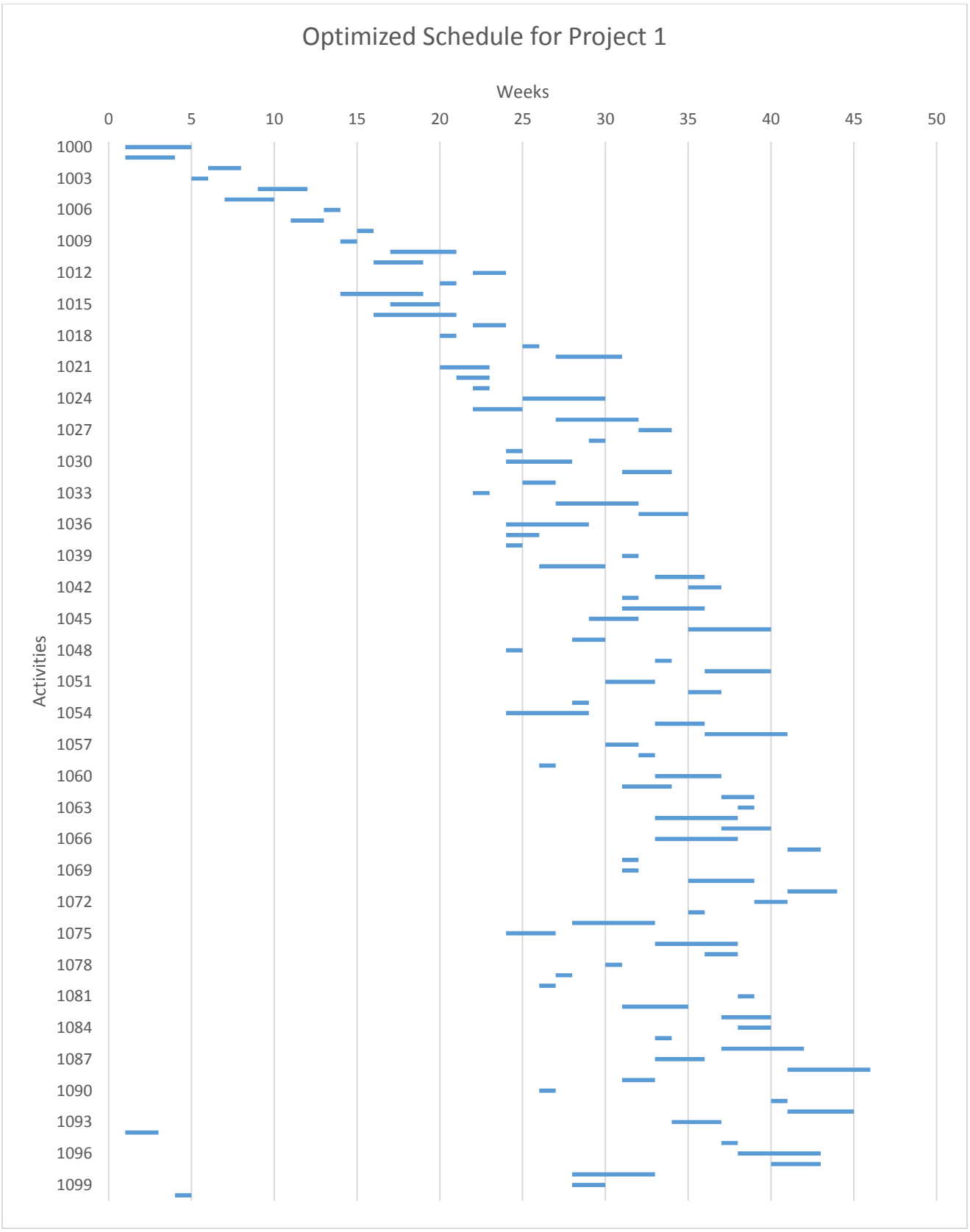


Figure 43 Optimized Schedule for Project 1

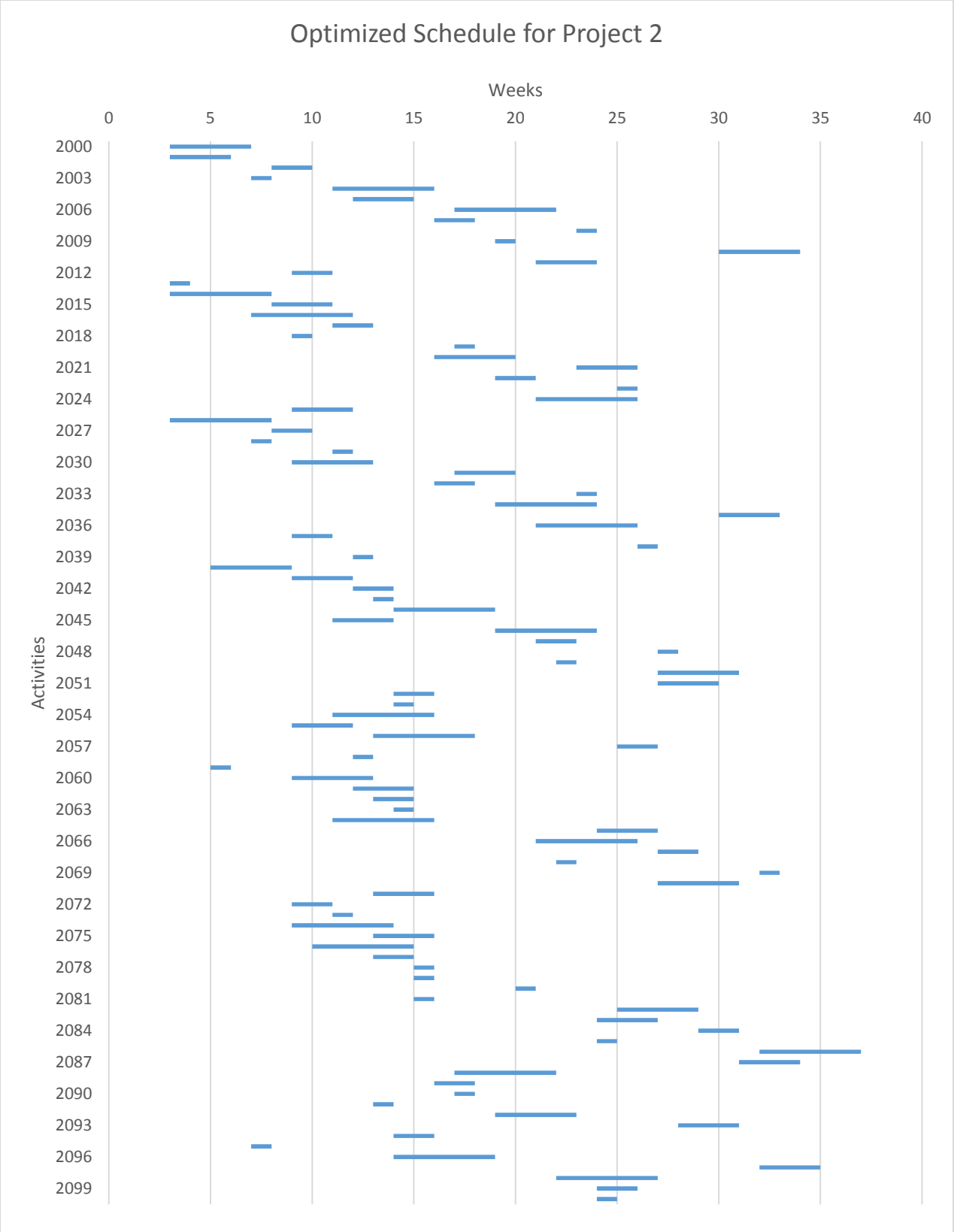


Figure 44 Optimized Schedule for Project 2

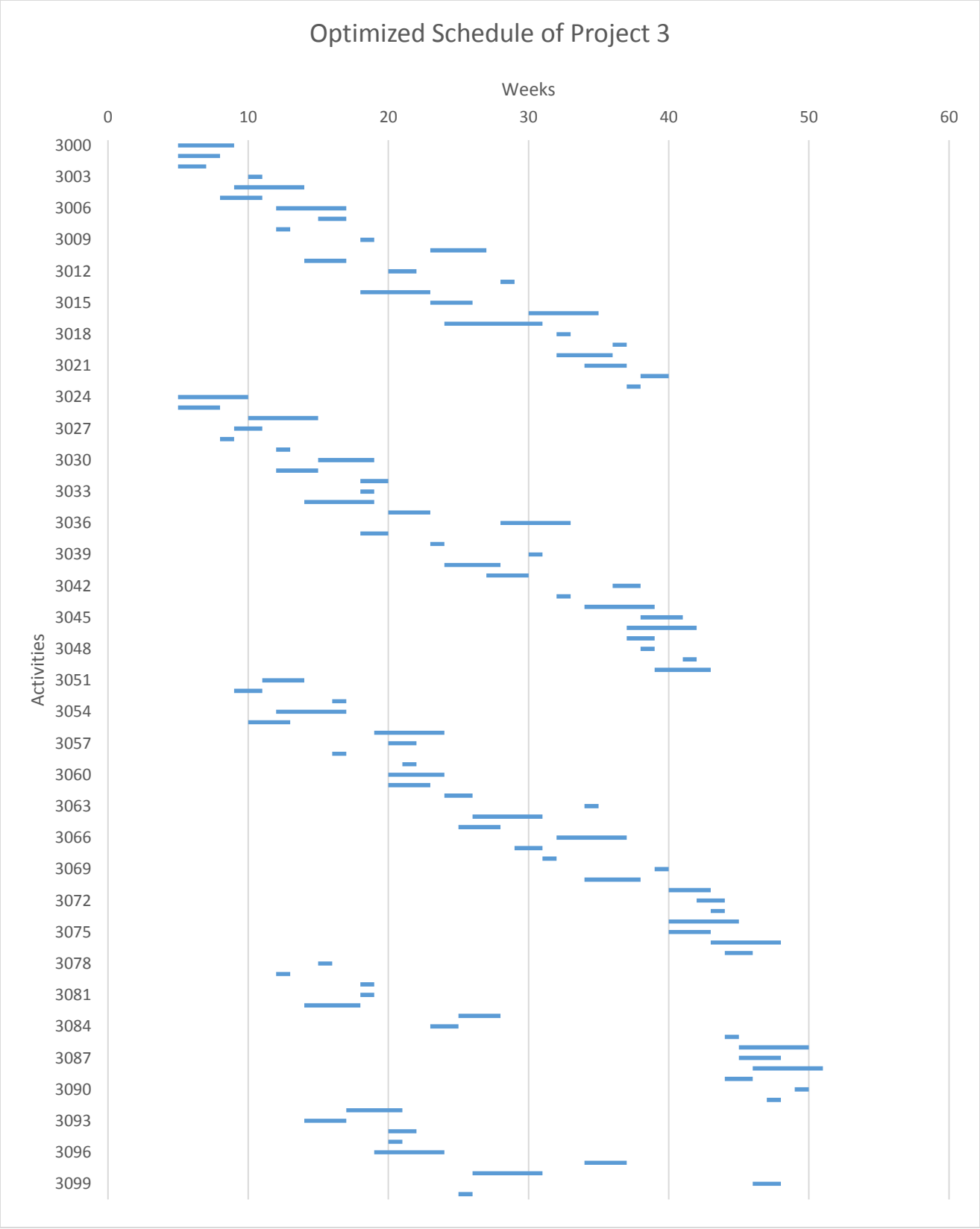


Figure 45 Optimized Schedule of Project 3

The bar charts of each resource is shown in Figure 46-Figure 54, showing the number of resources needed before and after optimization for each week during the project's duration, when the number of available pool of resources is reduced by 30% of the original needed resources.

Figure 46 shows that HR1 maximum weekly needed number before optimization was 21 and it was in week# 17 and week# 21. After optimization the maximum weekly needed number remained the same in Week#17, but decreased to 17 HR1 in week# 21 and the pool of available HR1 was 15 HR1. Overall, the total number of extra HR1 needed decreased by almost 50% which leads to decrease in the cost of extra resources.

Figure 47 shows that HR2 maximum number needed before optimization was 42 in week# 13 and week# 15. After optimization the maximum number of HR2 did not decrease that much and became 41, while the pool of available HR2 was 30 HR2. Overall, the total number of extra HR2 needed decreased less than 50% which leads to decrease in the cost of extra resources.

Figure 48 shows that HR3 maximum number needed before optimization was 39 in week#15. After optimization the maximum number of HR3 became 35, while the pool of available HR3 was 28 Hr3. Overall, the total number of extra HR3 needed decreased by over 50% which leads to decrease in cost of extra resources.

Figure 49 shows that ER1 maximum number needed before optimization was 40 in week# 36. After optimization the maximum number of ER1 became 35 but in week# 37, while the pool of available ER1 was 28 ER1. Overall, the total number of extra ER1 needed decreased by slightly less than 50% which leads to decrease in cost of extra resources.

Figure 50 shows that ER2 maximum number needed before optimization was 35 in week# 35. After optimization the maximum number of ER2 became 33 but in week# 14 and in week# 15, while the pool of available ER2 was 25 ER2. Overall, the total number of extra ER2 needed decreased by almost 50% which leads to decrease in cost of extra resources.

Figure 51 shows that ER3 maximum number needed before optimization was 47 in week# 14. After optimization the maximum number of ER3 became 45in week# 37, while the pool of available ER3 was 33 ER3. Overall, the total number of extra ER3 needed decreased by slightly less than 50% which leads to decrease in cost of extra resources.

Figure 52 shows that MR1 maximum number needed before optimization was 55 in week# 14. After optimization the maximum number of MR1 became 54 in week# 14 also, while the pool of available MR1 was 39 MR1. Overall, the total number of extra MR1 needed decreased by slightly more than 50% which leads to decrease in cost of extra resources.

Figure 53 shows that MR2 maximum number needed before optimization was 52 in week# 14. After optimization the maximum number of MR2 did not change and remained 52 MR2 in week# 14 also, while the pool of available MR2 was 37 MR2. Overall, the total number of extra MR2 needed decreased by almost 50% which leads to decrease in cost of extra resources.

Figure 54 shows that MR3 maximum number needed before optimization was 55 in week# 14. After optimization the maximum number of MR3 became 52 in week# 14 also, while the pool of available MR3 was 39 MR3. Overall, the total number of extra MR1 needed decreased by almost 50% which leads to decrease in cost of extra resources.

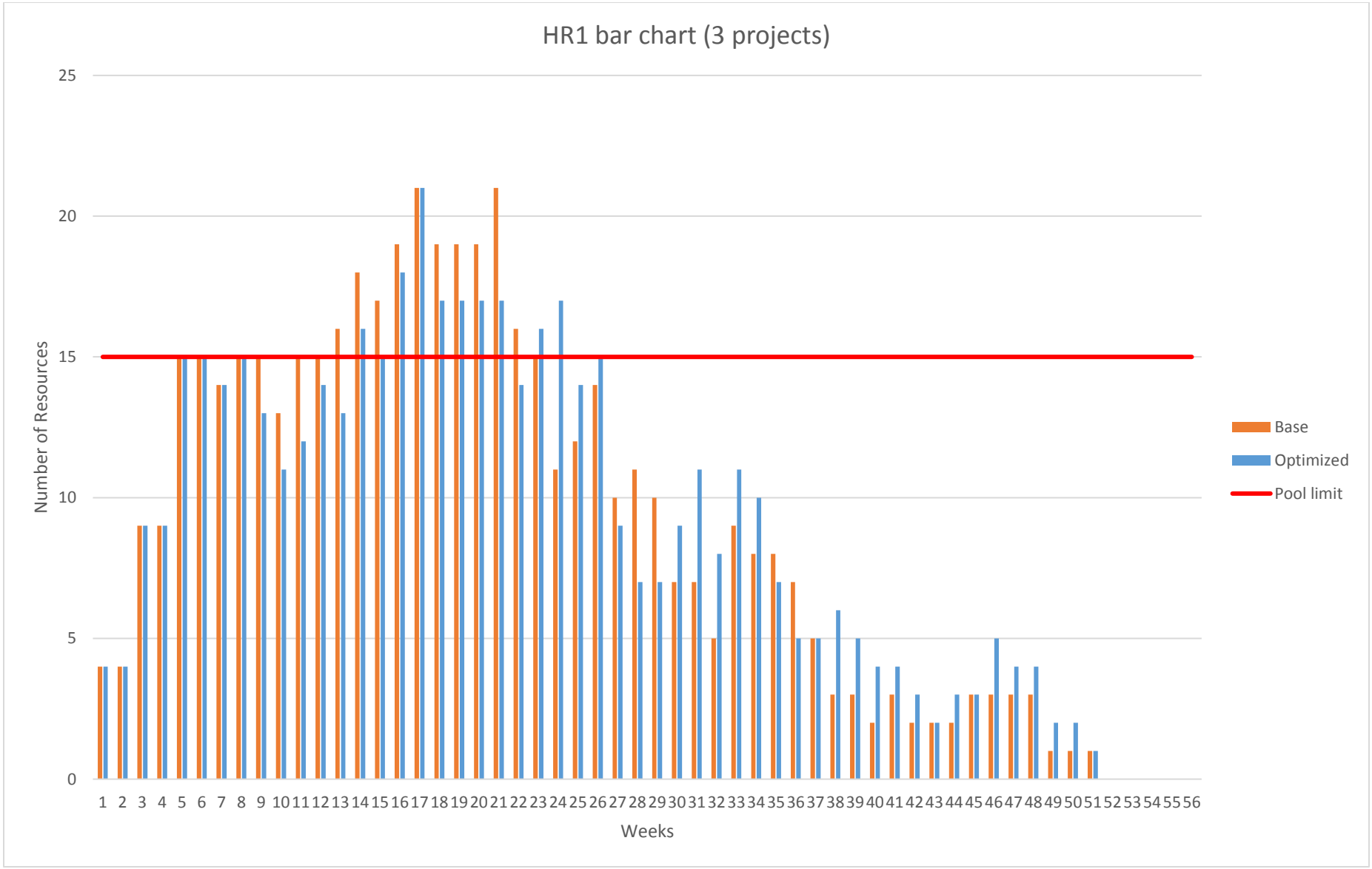


Figure 46 HR1 bar chart (3 projects)

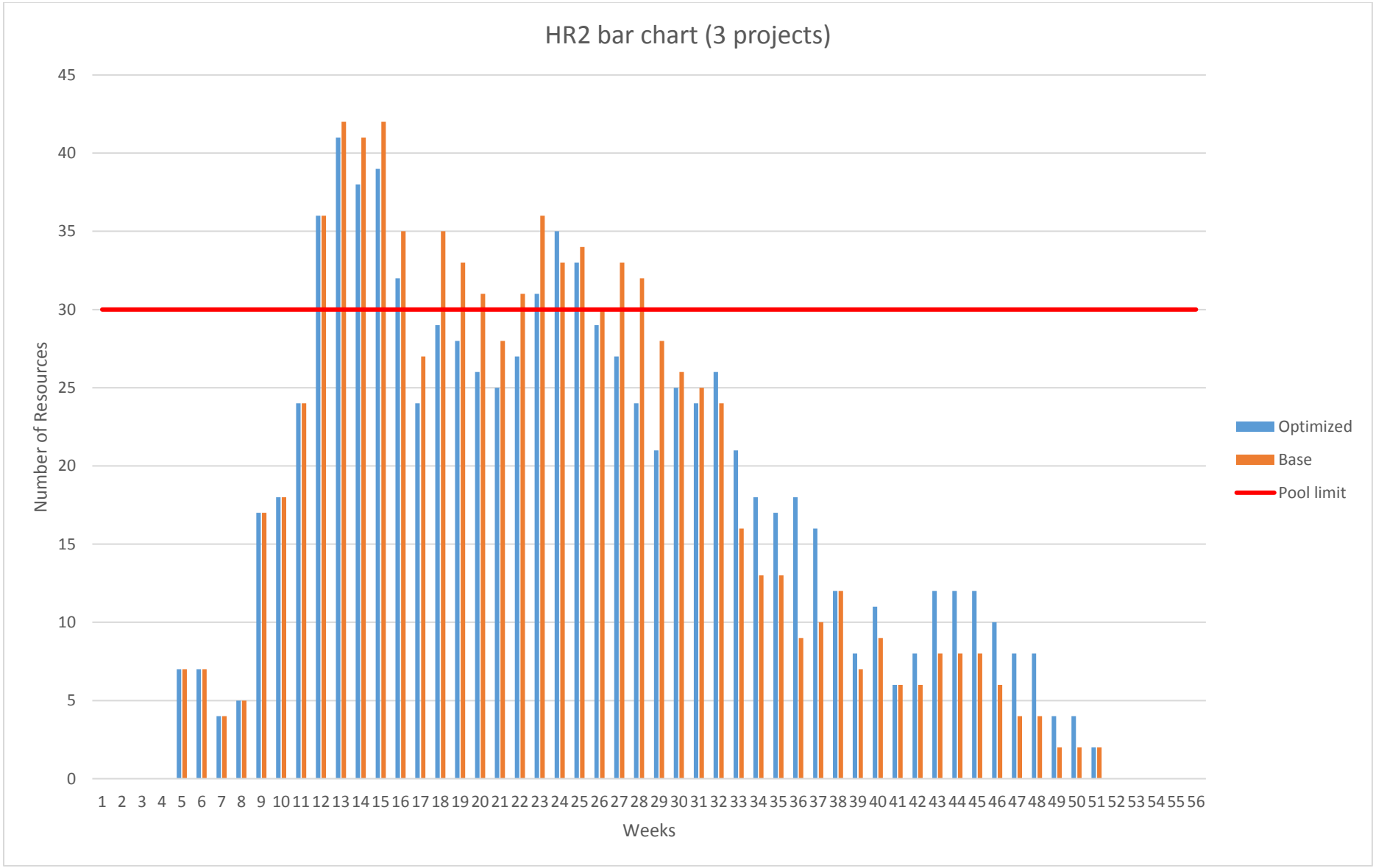


Figure 47 HR2 bar chart (3 projects)

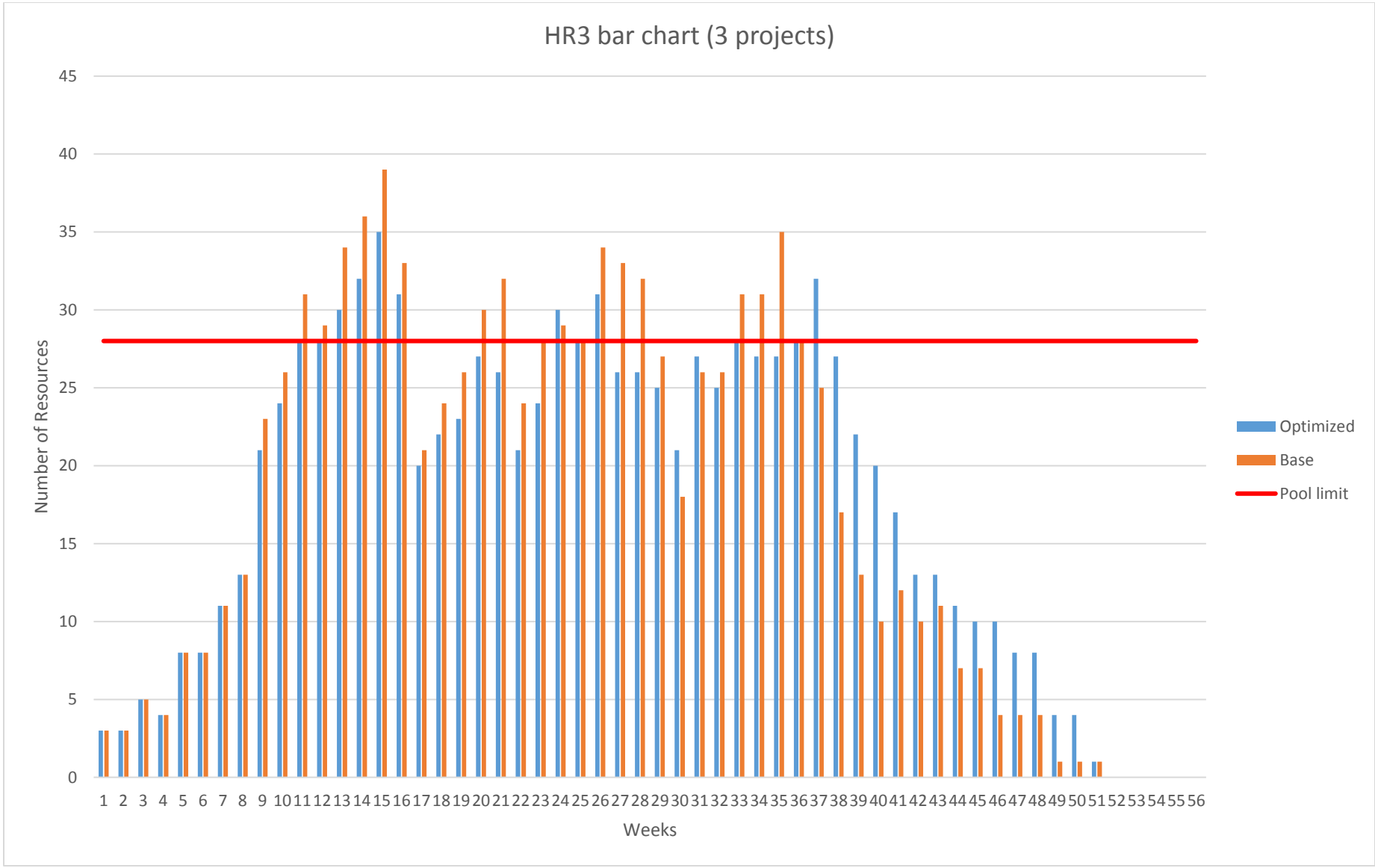


Figure 48 HR3 bar chart (3 projects)

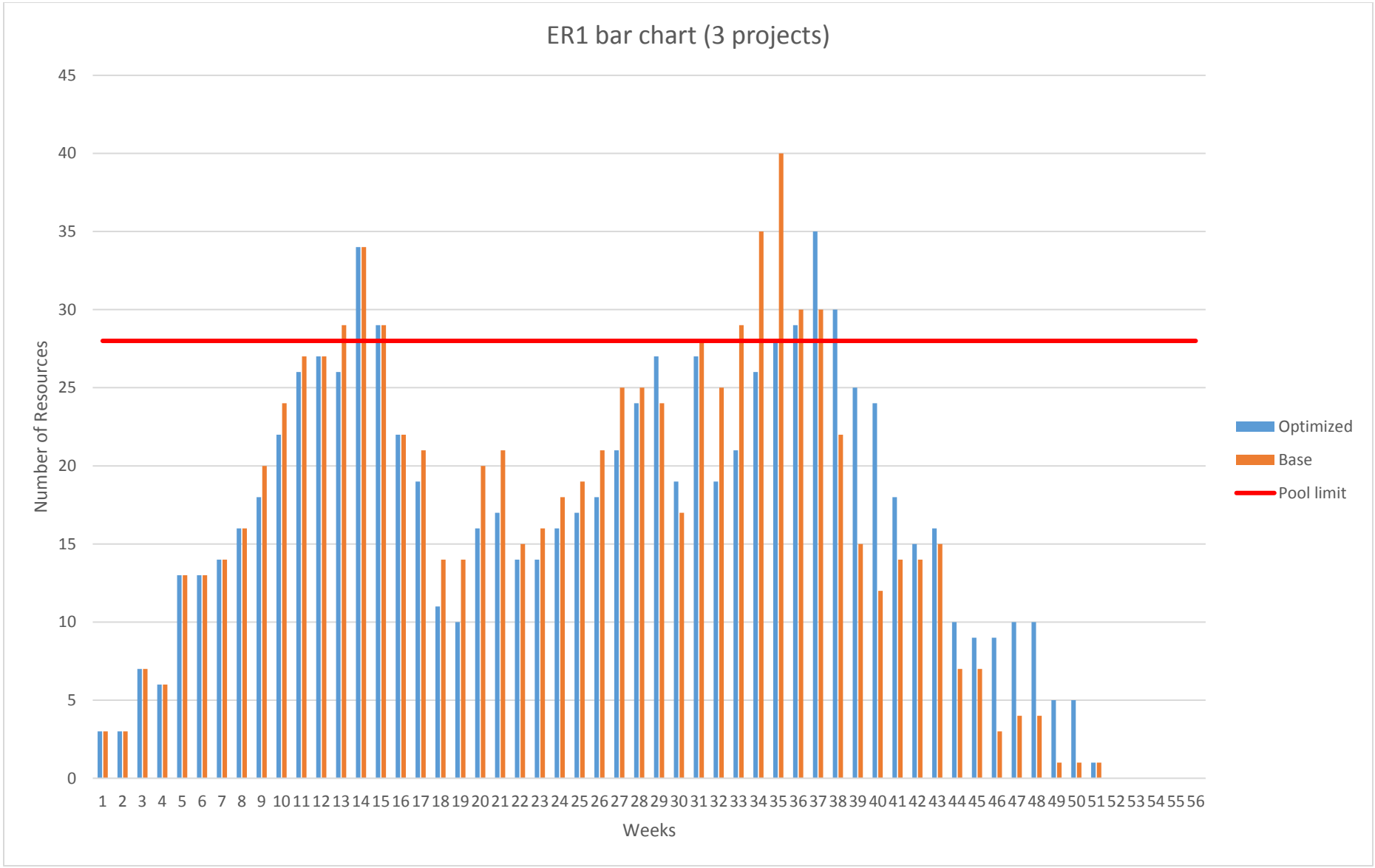


Figure 49 ER1 bar chart (3 projects)

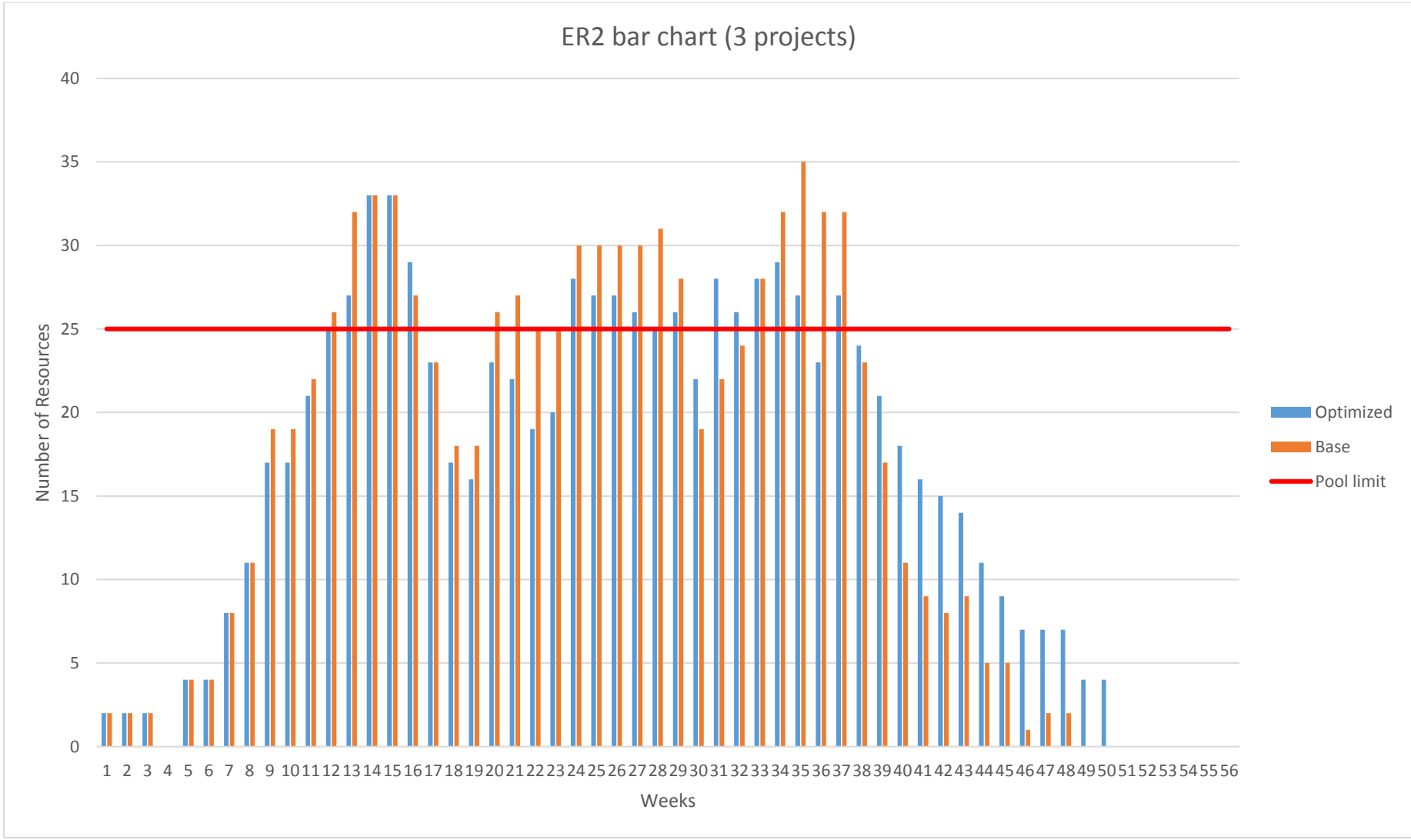


Figure 50 ER2 bar chart (3 projects)

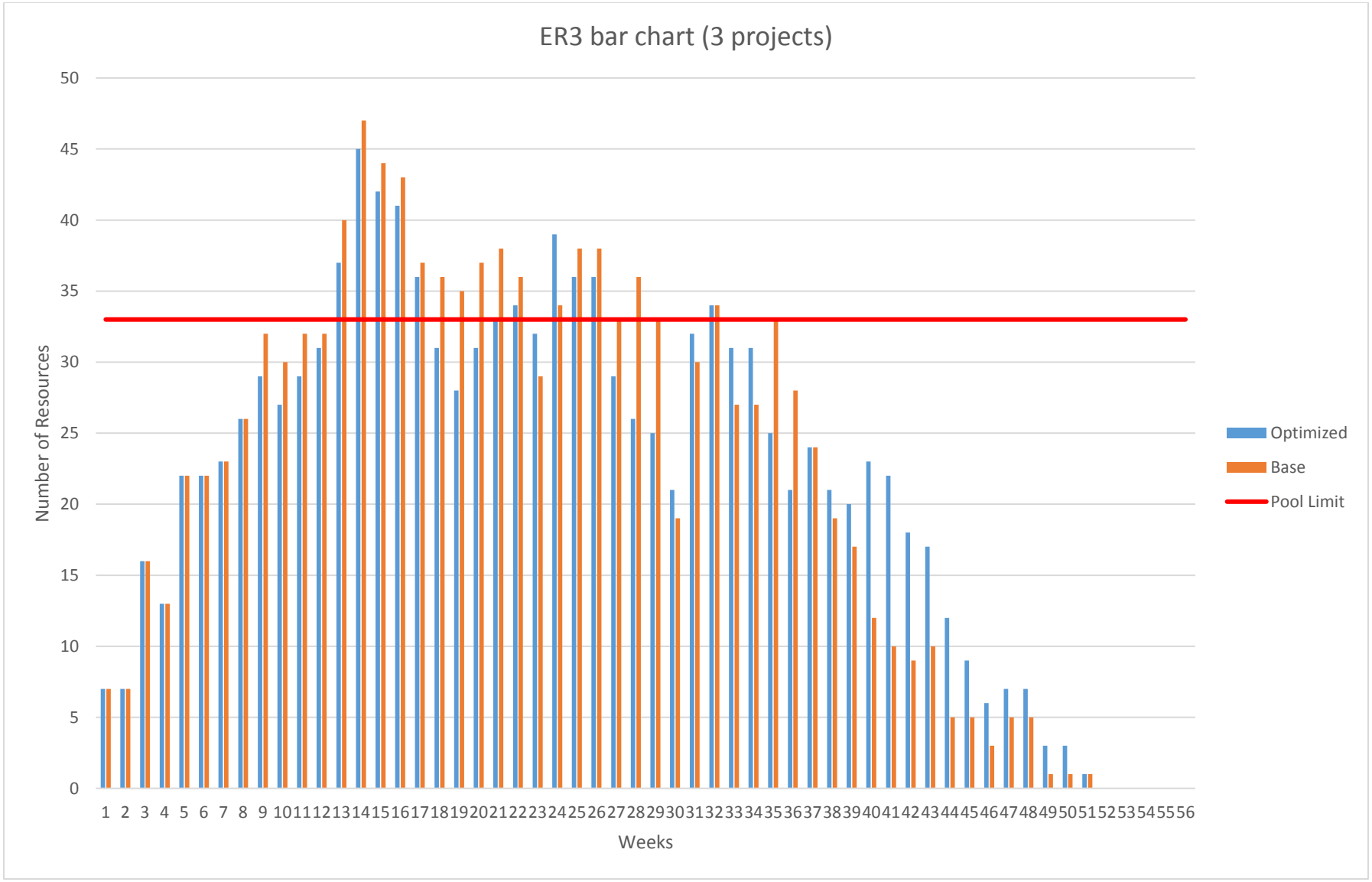


Figure 51 ER3 bar chart (3 projects)

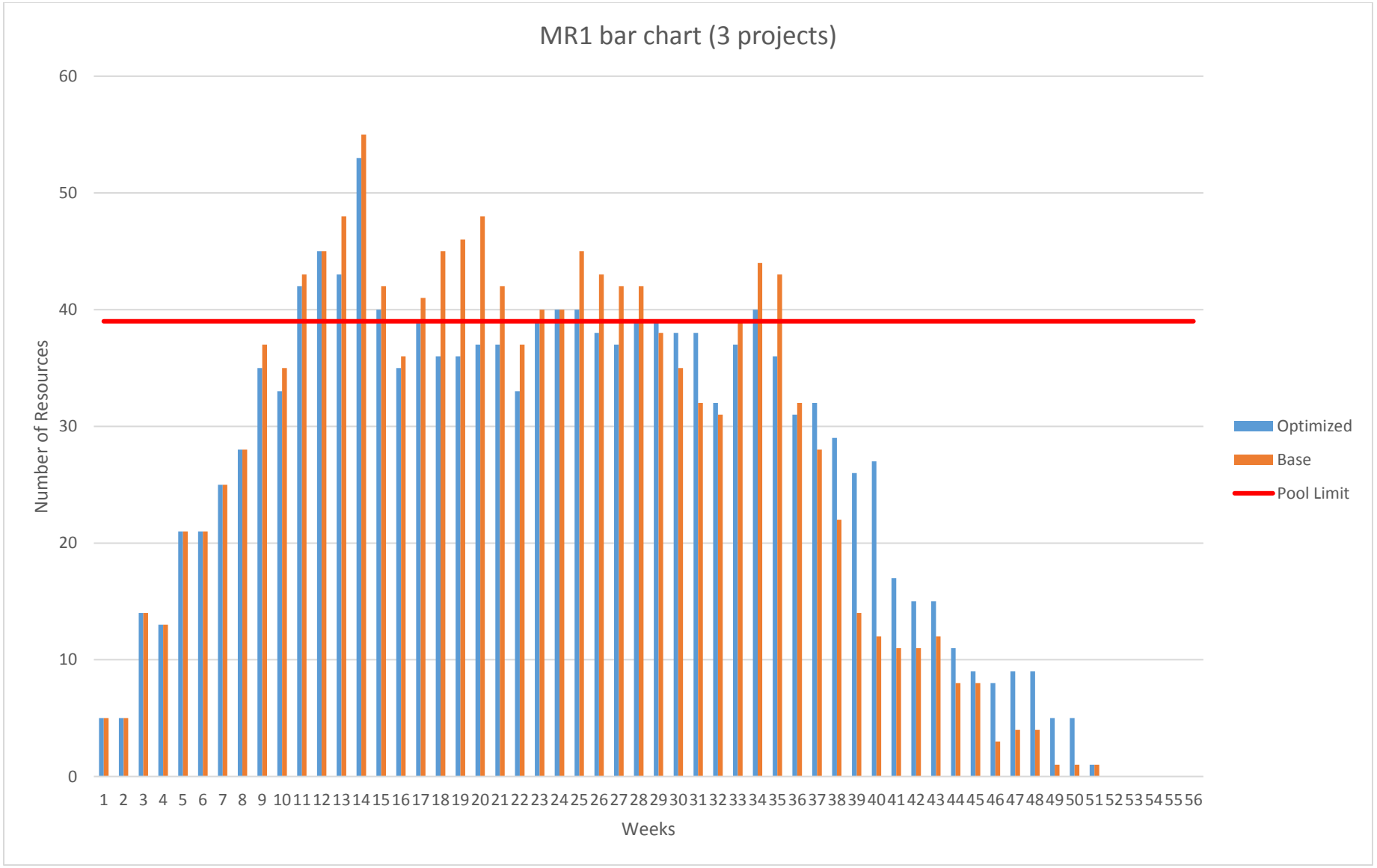


Figure 52 MR1 bar chart (3 projects)

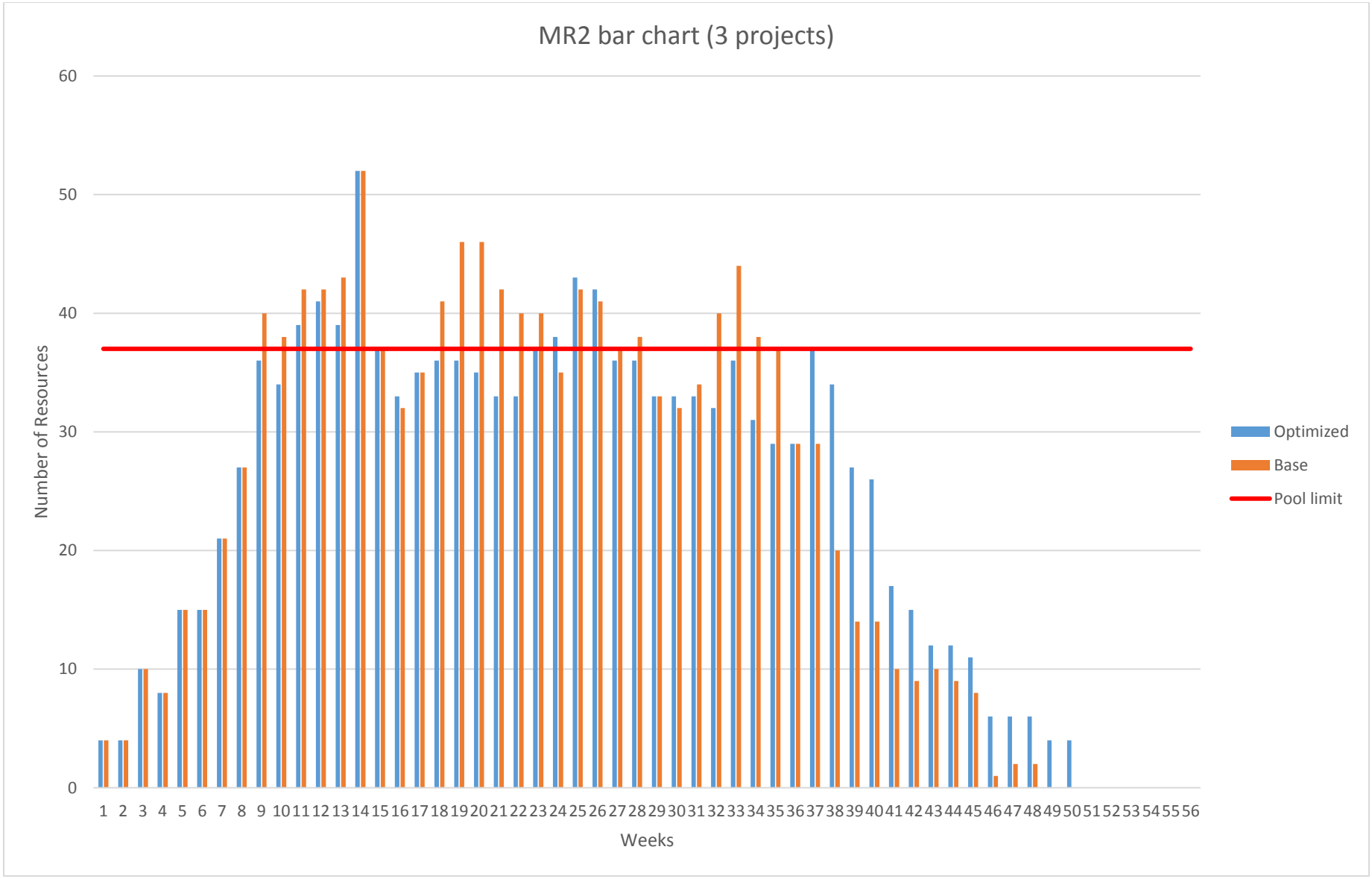


Figure 53 MR2 bar chart (3 projects)

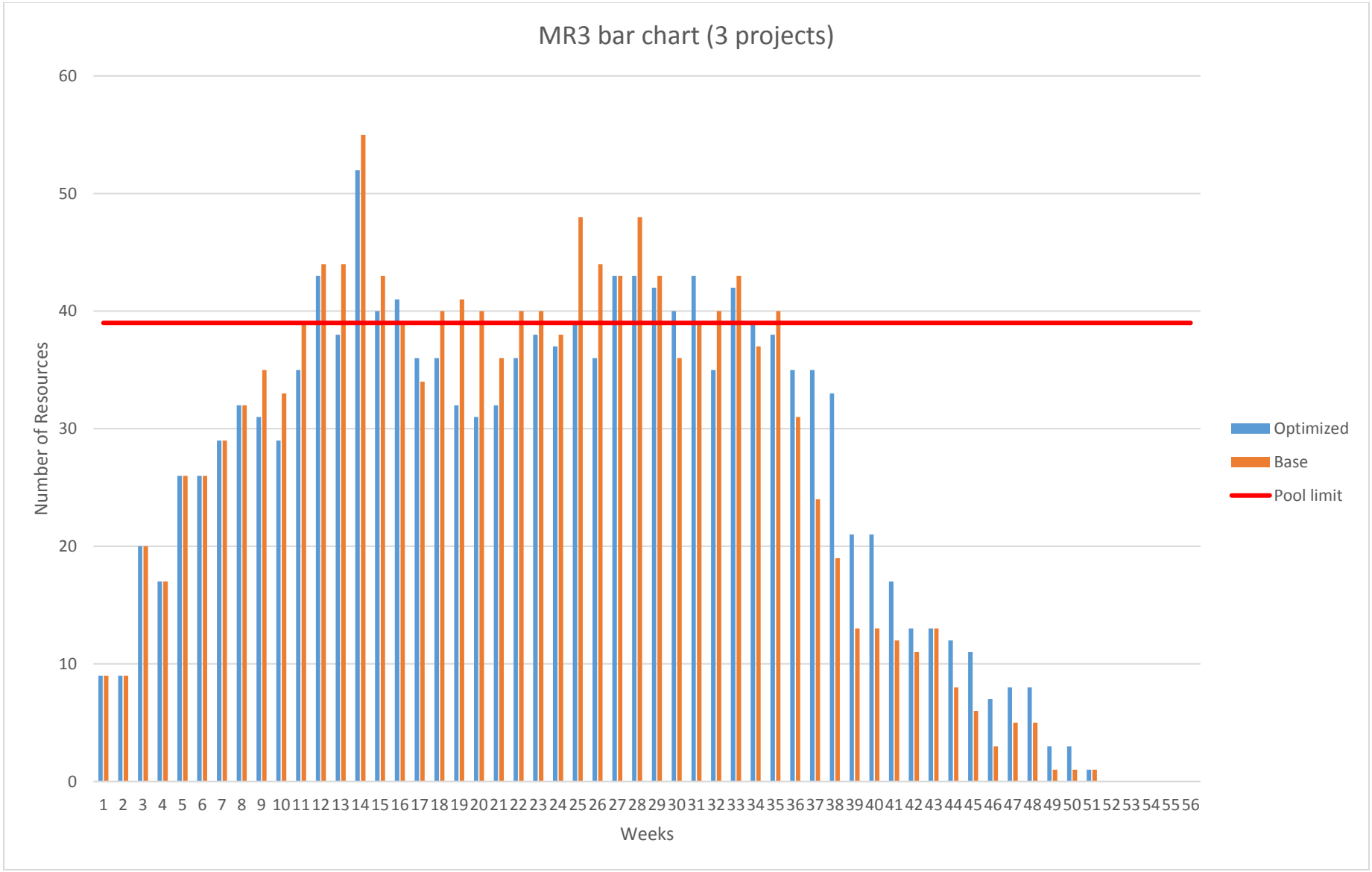


Figure 54 MR3 bar chart (3 projects)

From Figure 46 HR1 bar chart (3 projects)Figure 39 till Figure 54 , the model was able to decrease the cost of extra resources for the whole portfolio; without extending the deadline of any project; by more than 60%. This might not be the case for other projects or other portfolios, as each project is unique and has its own circumstances and conditions. Above this, combining several projects together would be harder to predict how would they affect each other and affect the whole portfolio.

4.5 Multiple resources of 3 projects extending the deadlines

The model was tested on multiple resources of three projects allowing extension of the duration of each project by 5%, 7% and 10%. The cost of extra resources decreased significantly compared to maintaining the deadlines of the project; as shown in **Error! Reference source not found.**. The maximum pool of resources was decreased by 30% from the maximum required.

When the durations of projects were increased by 5%, the cost of extra resources was decreased by 86% compared to maintaining the deadlines of the projects. When the durations of projects were increased by 7%, the cost of extra resources was decreased by 96.5% compared to maintaining the deadlines of the projects. When the durations of projects were increased by 10%, the cost of extra resources was decreased by 98% compared to maintaining the deadlines of the projects.

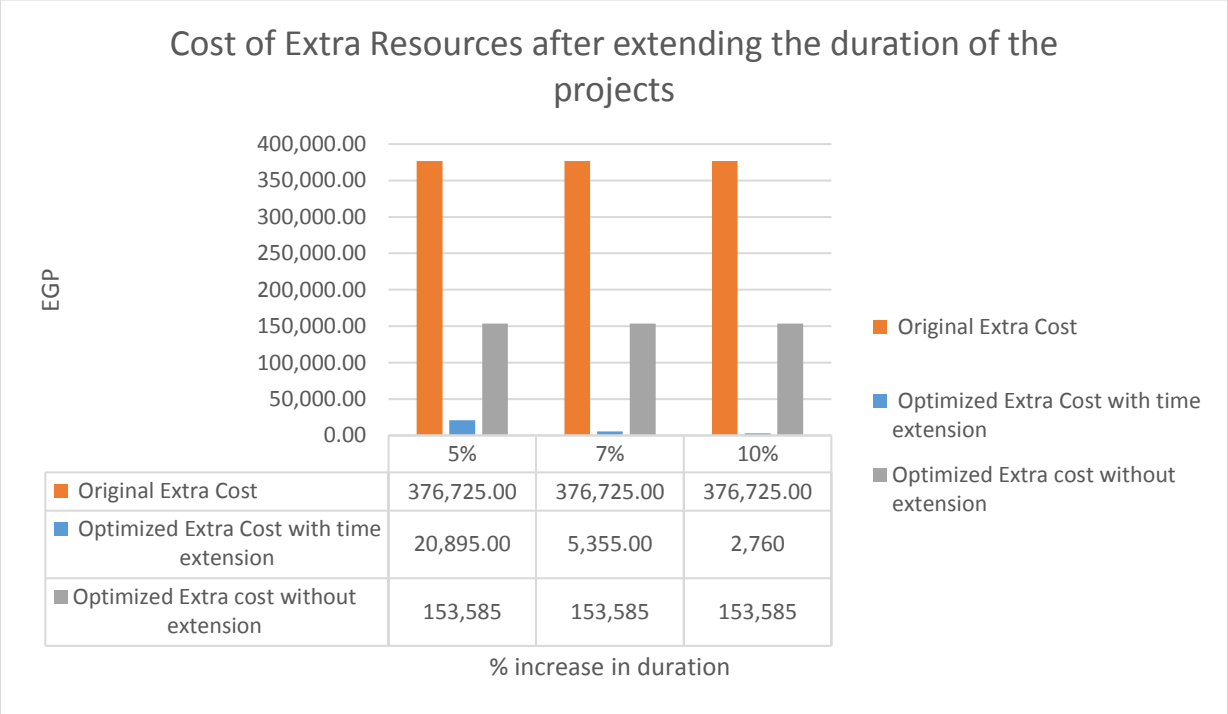


Figure 55 Cost of Extra Resources after extending the durations of the projects

Table 7 Start and End Weeks of the three projects before and after optimization allowing 10% extension of time

3 projects optimization allowing time extension				
	Before Optimization		After Optimization	
	Start Week	End Week	Start Week	End Week
Project 1	1	46	1	50
Project 2	3	37	3	40
Project 3	5	51	5	54

Table 7 summarized the start week and end week of each project before and after optimization and allowing 10% extension of time.

Figure 56 shows the updated schedule of project 1 after optimization allowing 10% increase in the project duration. Therefore project 1 finished on week 50 instead of week 46 as in Figure 40.

Figure 57 shows the updated schedule of project 2 after optimization allowing 10% increase in the project duration. Therefore project 2 finished on week 40 instead of week 37 as in Figure 41.

Figure 58 shows the updated schedule of project 3 after optimization allowing 10% increase in the project duration. Therefore project 3 finished on week 54 instead of week 50 as in Figure 42.

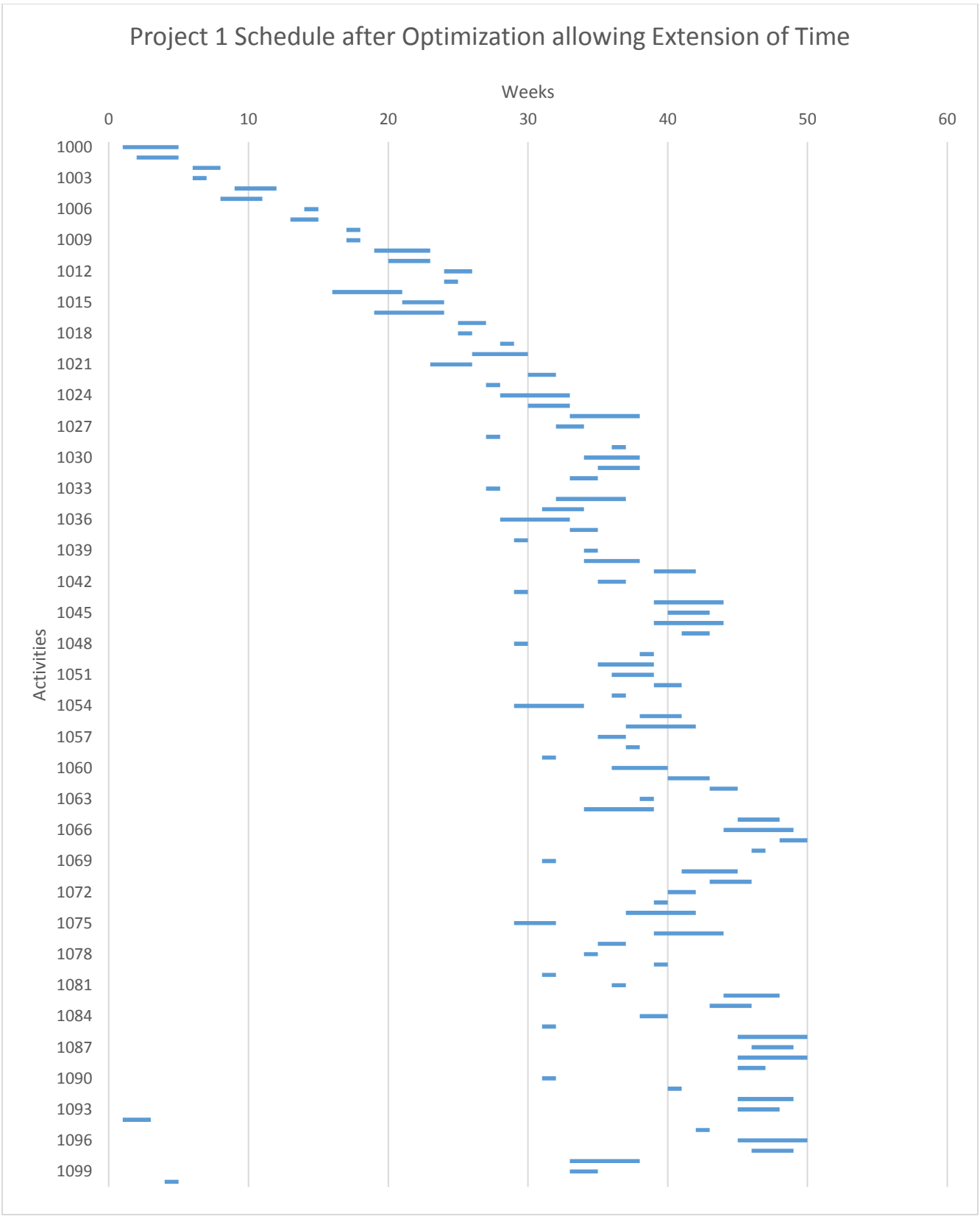


Figure 56 Project 1 Schedule after optimization allowing time extension

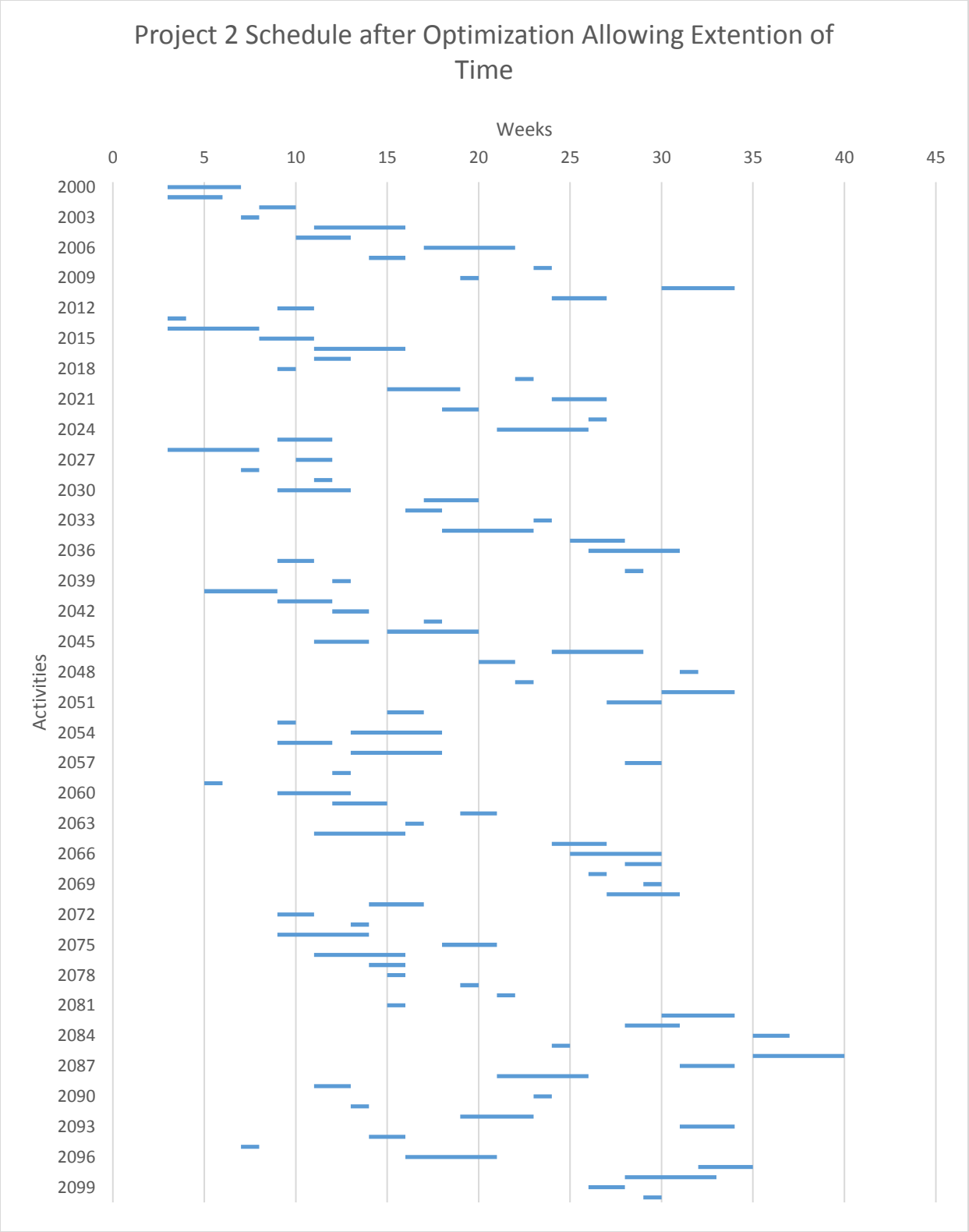


Figure 57 Project 2 Schedule after optimization allowing time extension

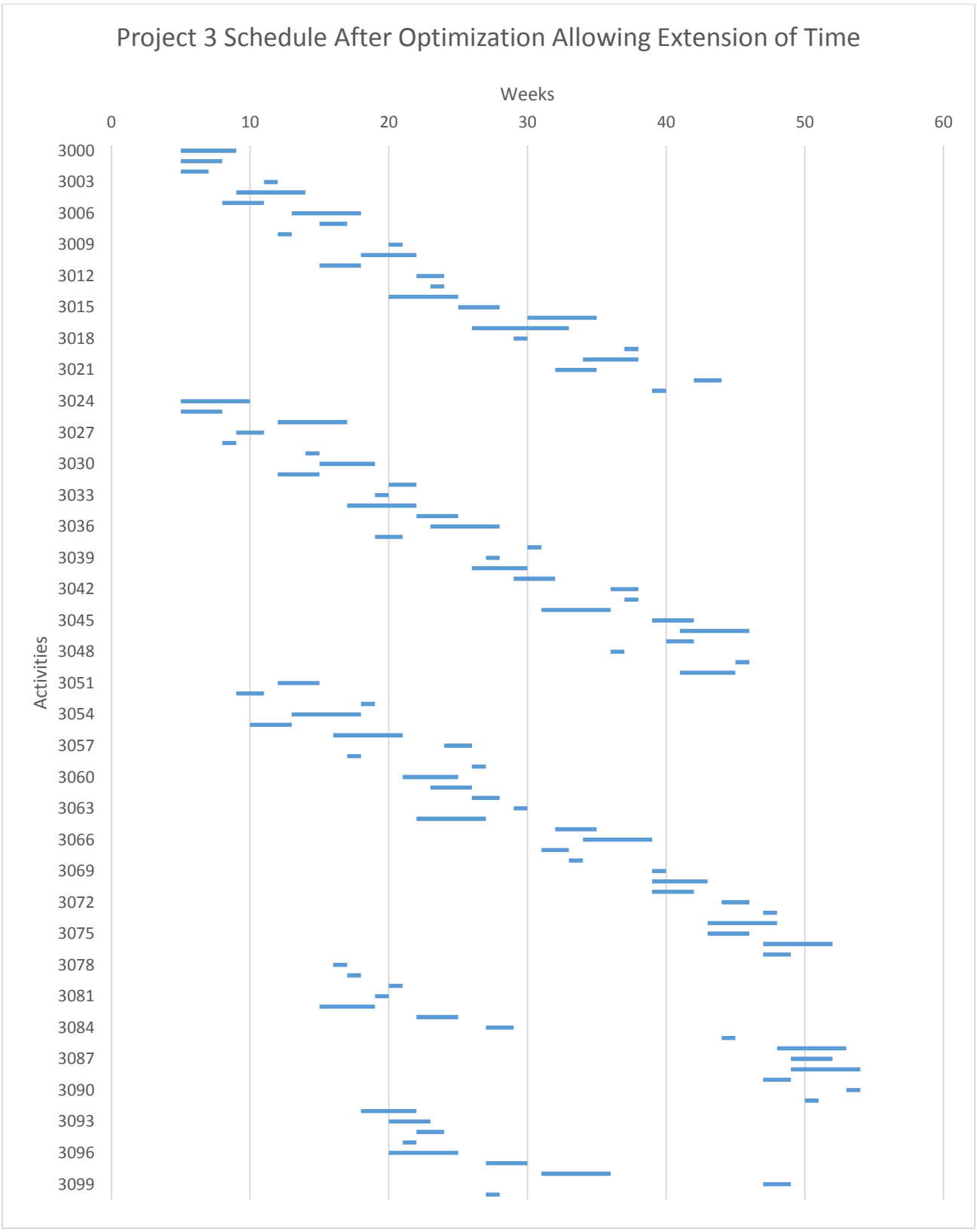


Figure 58 Project 3 Schedule after optimization allowing time extension

Figure 59 shows that maximum number of HR1 needed; while the pool of available HR1 was 15 only; before optimization was 21 HR1, after optimization it remained the same, but when a time extension was allowed the maximum number of HR1 decreased slightly to be 20 HR1. Overall, after allowing extension of time, the cost of extra HR1 decreased by more than 70%.

Figure 60 shows that maximum number of HR2 needed; while the pool of available HR2 was 30 only; before optimization was 42 HR2, after optimization it decreased to be 41 HR2, but when a time extension was allowed the maximum number of HR2 decreased to be 36 HR2. Overall, after allowing extension of time, the cost of extra HR2 decreased by more than 80%.

Figure 61 shows that maximum number of HR3 needed; while the pool of available HR3 was 28 only; before optimization was 39 HR3, after optimization it decreased to be 35 HR3, but when a time extension was allowed the maximum number of HR3 decreased to be 31 HR3. Overall, after allowing extension of time, the cost of extra HR3 decreased by more than 90%.

Figure 62 shows that maximum number of ER1 needed; while the pool of available ER1 was 28 only; before optimization was 40 ER1, after optimization it decreased to be 35 ER1, but when a time extension was allowed the maximum number of ER1 decreased to be 29 ER1. Overall, after allowing extension of time, the cost of extra ER1 decreased by more than 95%.

Figure 63 shows that maximum number of ER2; while the pool of available ER2 was 25 only; before optimization was 35 ER2, after optimization it decreased to be 33 ER2, but when a time extension was allowed the maximum number of ER2 decreased to be 25 ER2 as the pool limit. Overall, after allowing extension of time, the cost of extra ER2 was eliminated.

Figure 64 shows that maximum number of ER3 needed; while the pool of available ER3 was 33 only; before optimization was 47 ER3, after optimization it decreased to be 45 ER3, but when a time extension was allowed the maximum number of ER3 decreased to be 33 ER3 as the pool available. Overall, after allowing extension of time, the cost of extra ER3 was eliminated.

Figure 65 shows that maximum number of MR1 needed; while the pool of available MR1 was 39 only; before optimization was 55 MR1, after optimization it decreased to be 54 MR1, but when a time extension was allowed the maximum number of MR1 decreased to be 39 MR1 as the pool available. Overall, after allowing extension of time, the cost of extra MR1 was eliminated.

Figure 66 shows that maximum number of MR2 needed; while the pool of available MR2 was 37 only; before optimization was 52 MR2, after optimization it remained the same, but when a time extension was allowed the maximum number of MR2 decreased to be 38 MR2 just above the pool limit and for only week# 11. Overall, after allowing extension of time, the cost of extra MR2 decreased by more than 98%.

Figure 67 shows that maximum number of MR3 needed; while the pool of available MR3 was 39 only; before optimization was 55 MR3, after optimization it decreased to be 52 MR3, but when a time extension was allowed the maximum number of MR3 decreased to be 40 MR3 just above the pool limit and for only week# 30. Overall, after allowing extension of time, the cost of extra MR3 decreased by more than 98%.

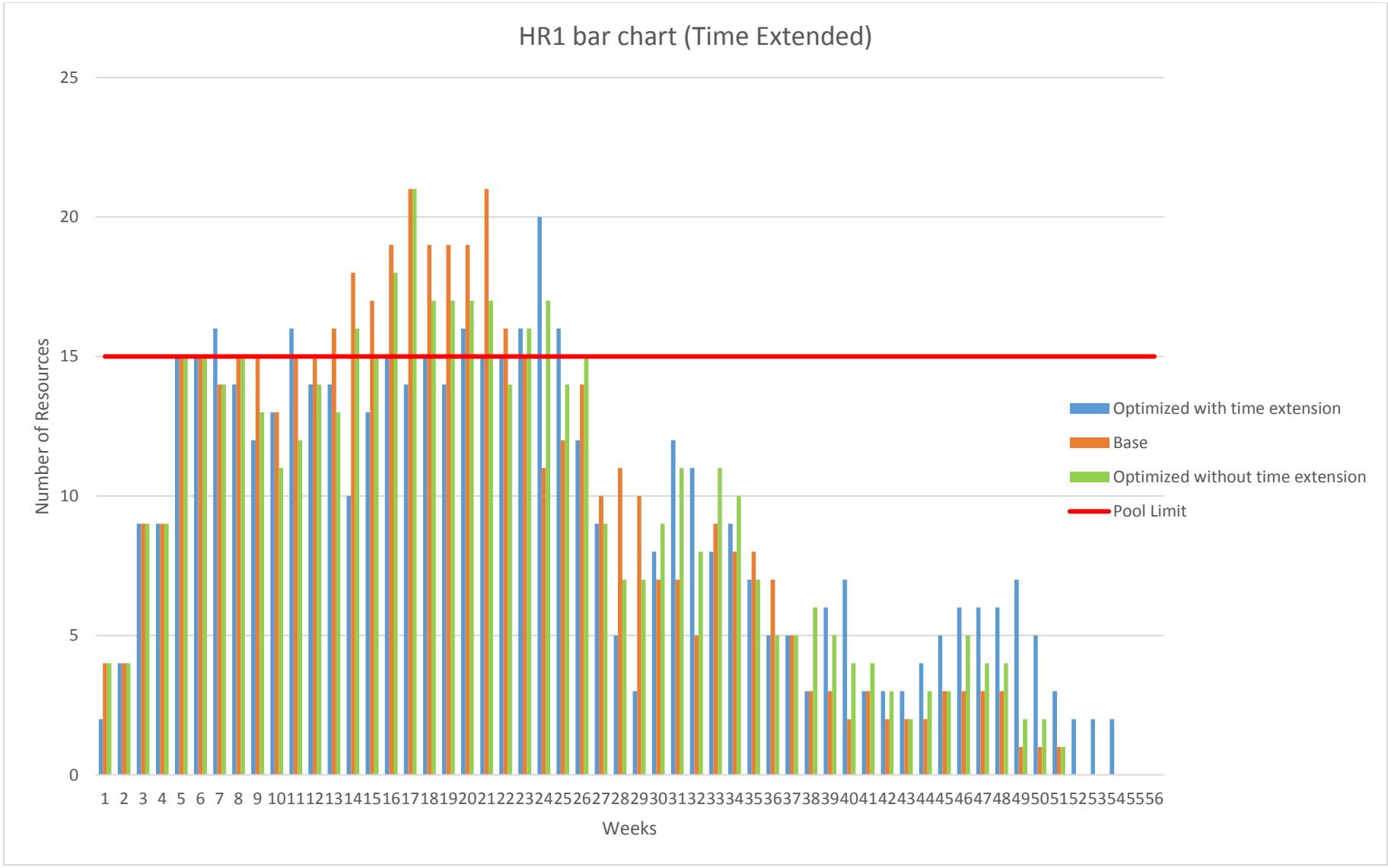


Figure 59 HR1 bar chart (Time Extended)

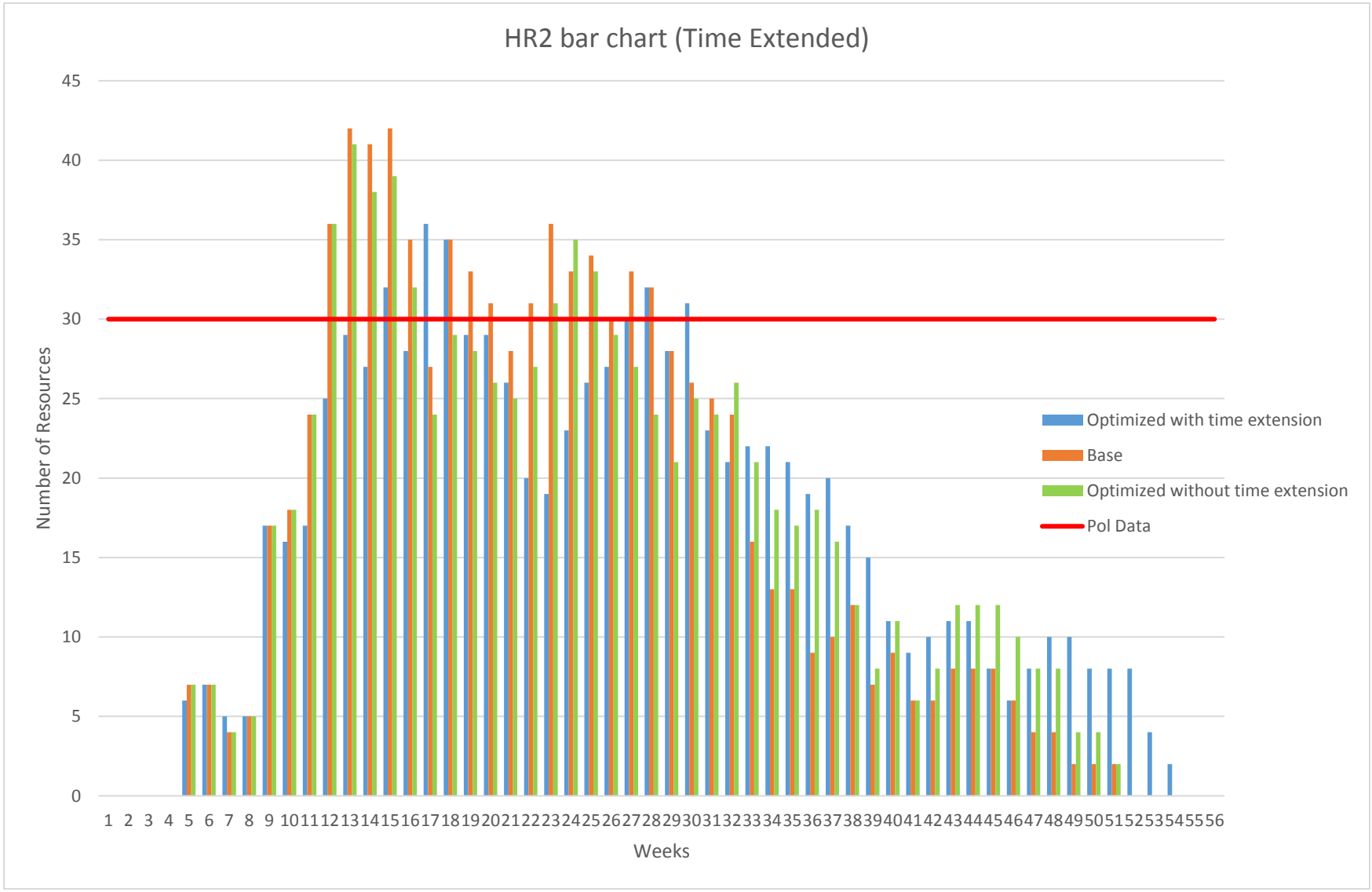


Figure 60 HR2 bar chart (Time Extended)

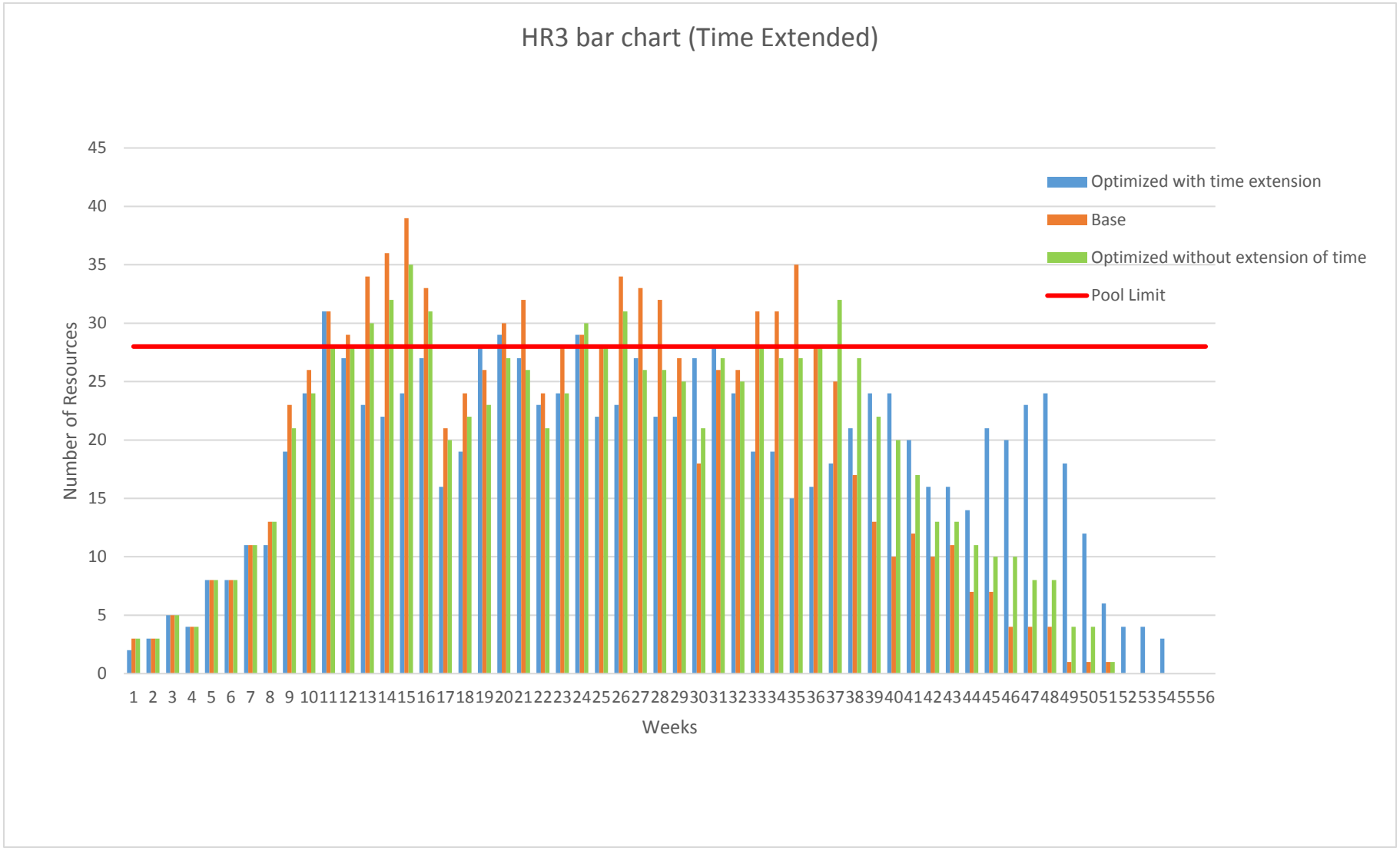


Figure 61 HR3 bar chart (Time Extended)

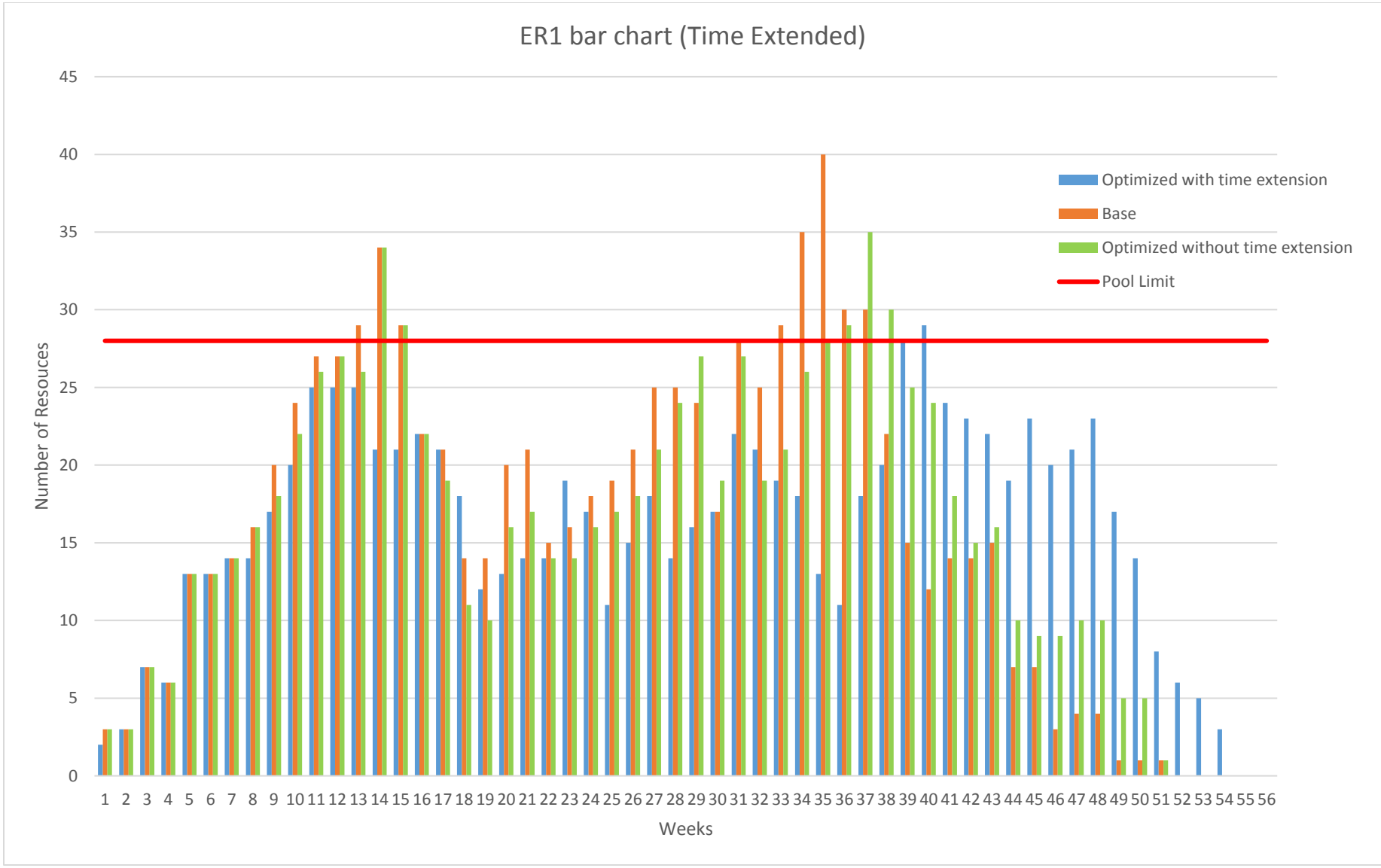


Figure 62 ER1 bar chart (Time Extended)

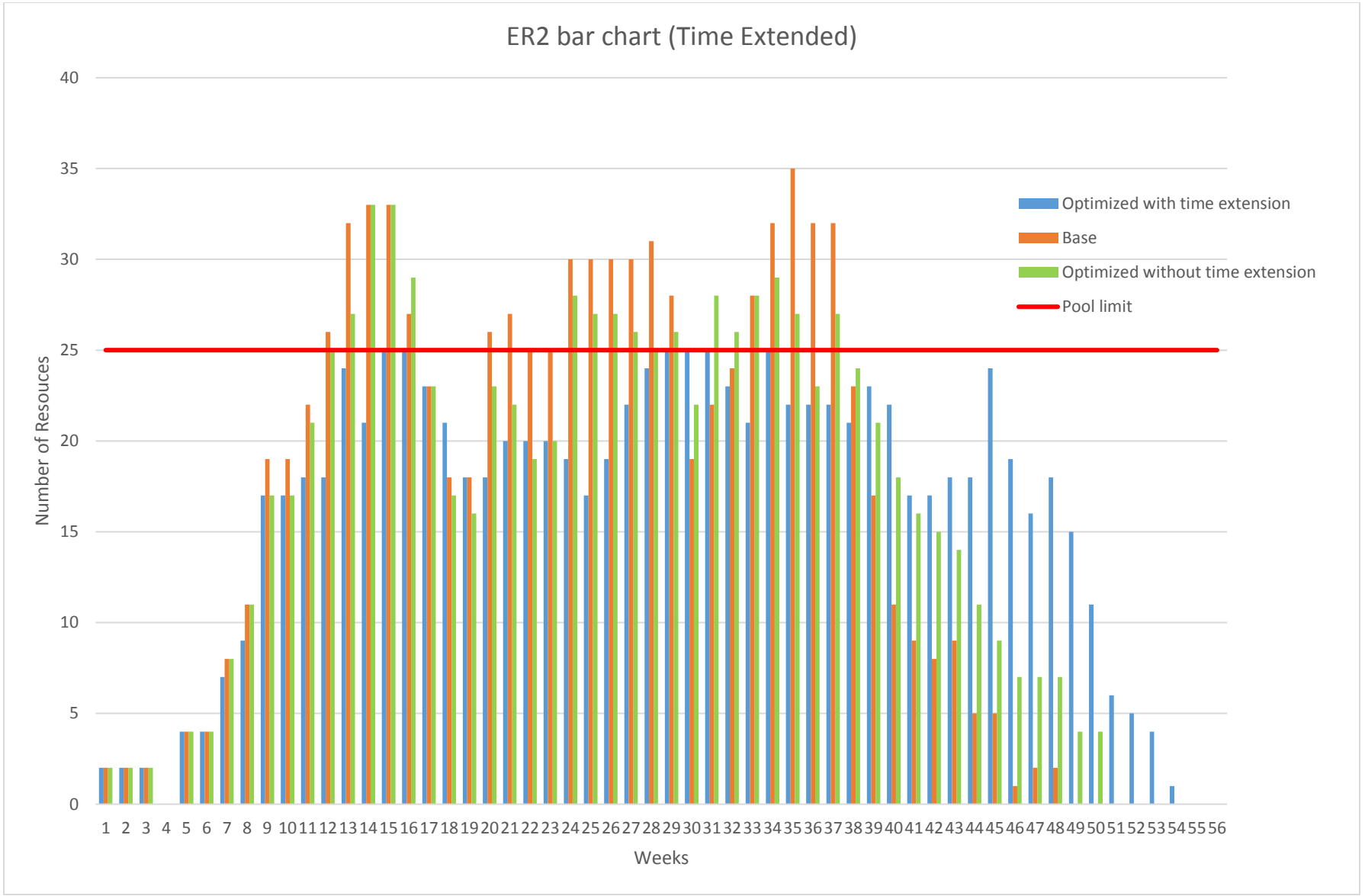


Figure 63 ER2 bar chart (Time Extended)

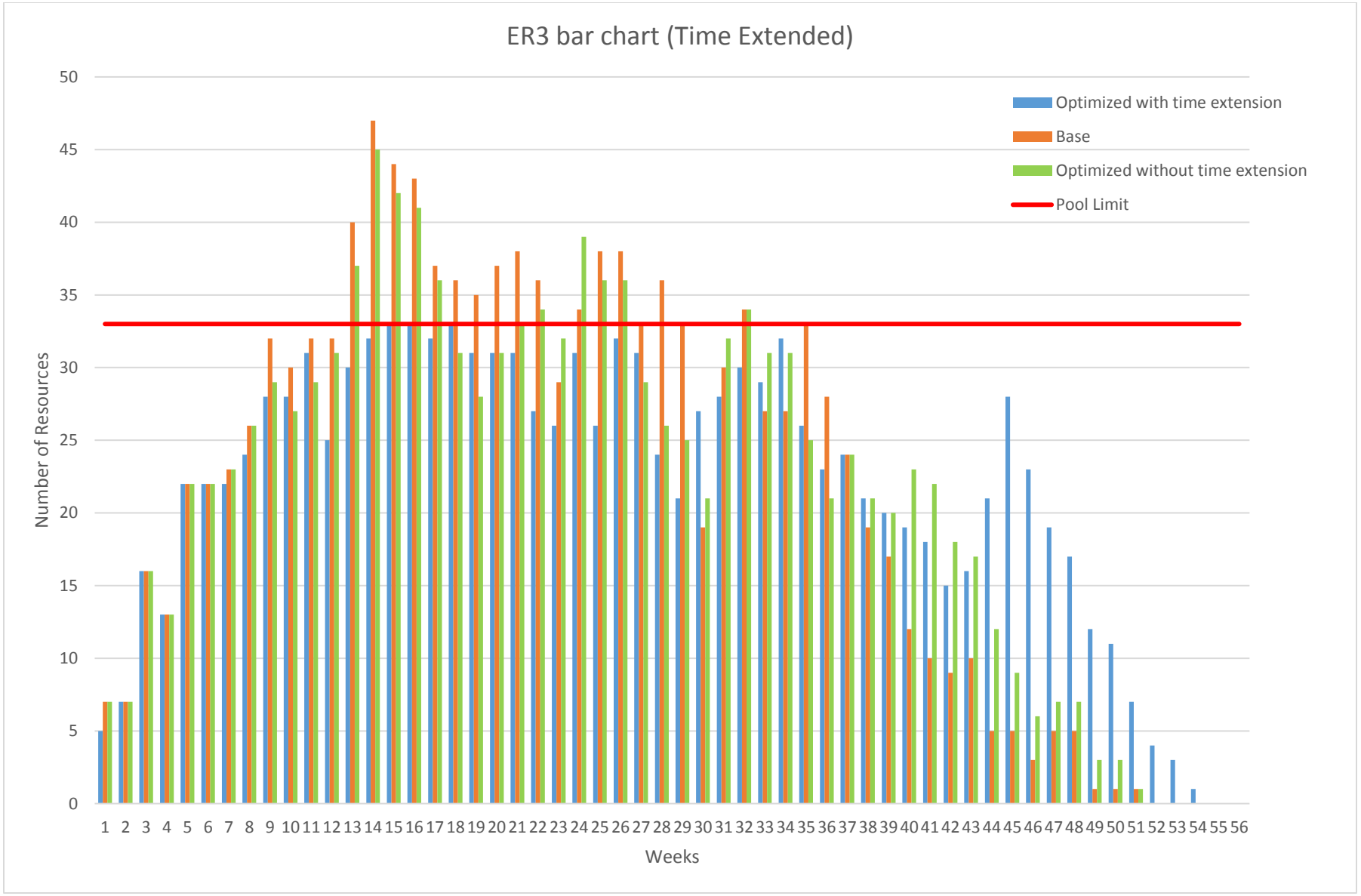


Figure 64 ER3 bar chart (Time Extended)

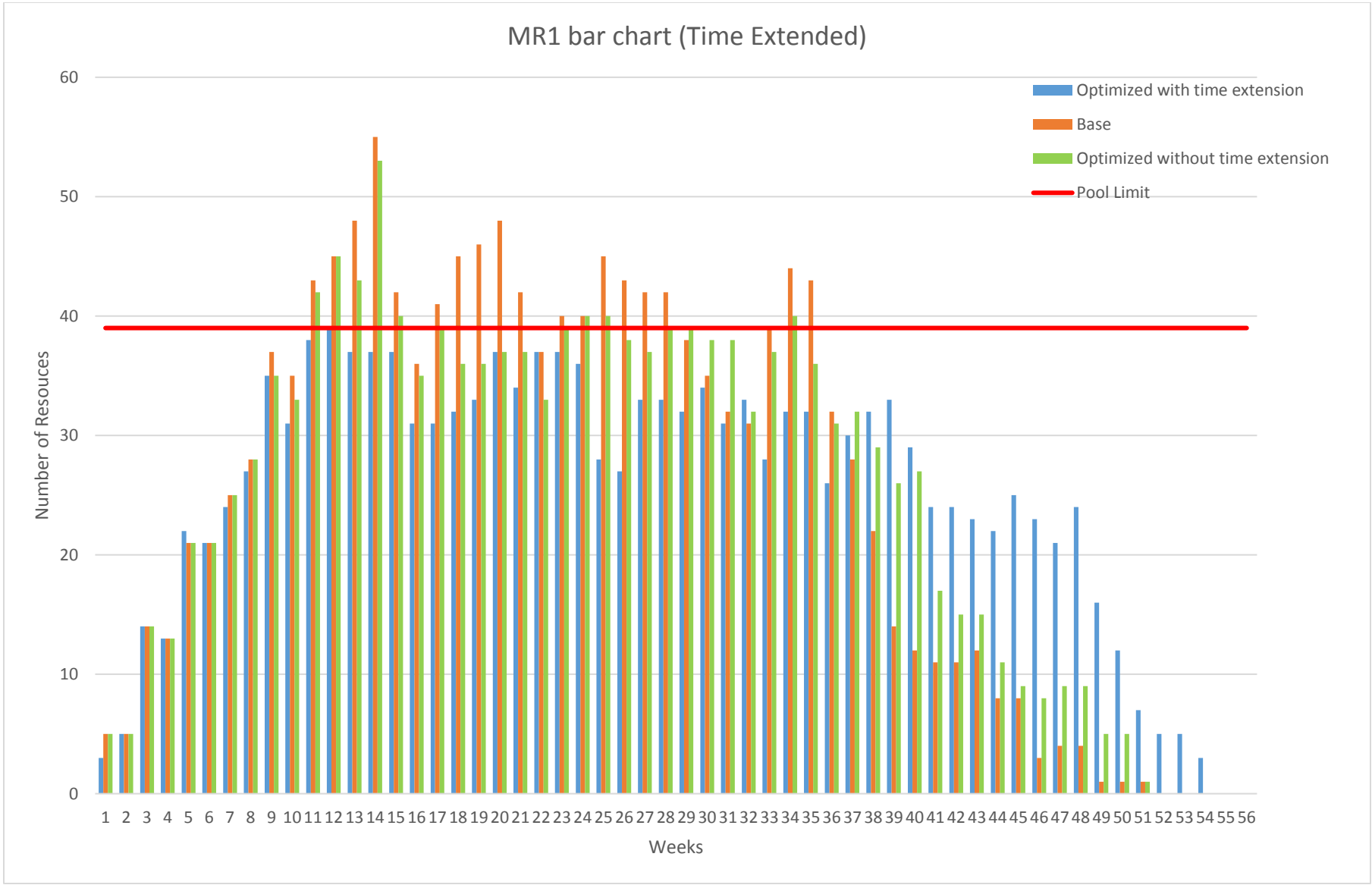


Figure 65 MR1 bar chart (Time Extended)

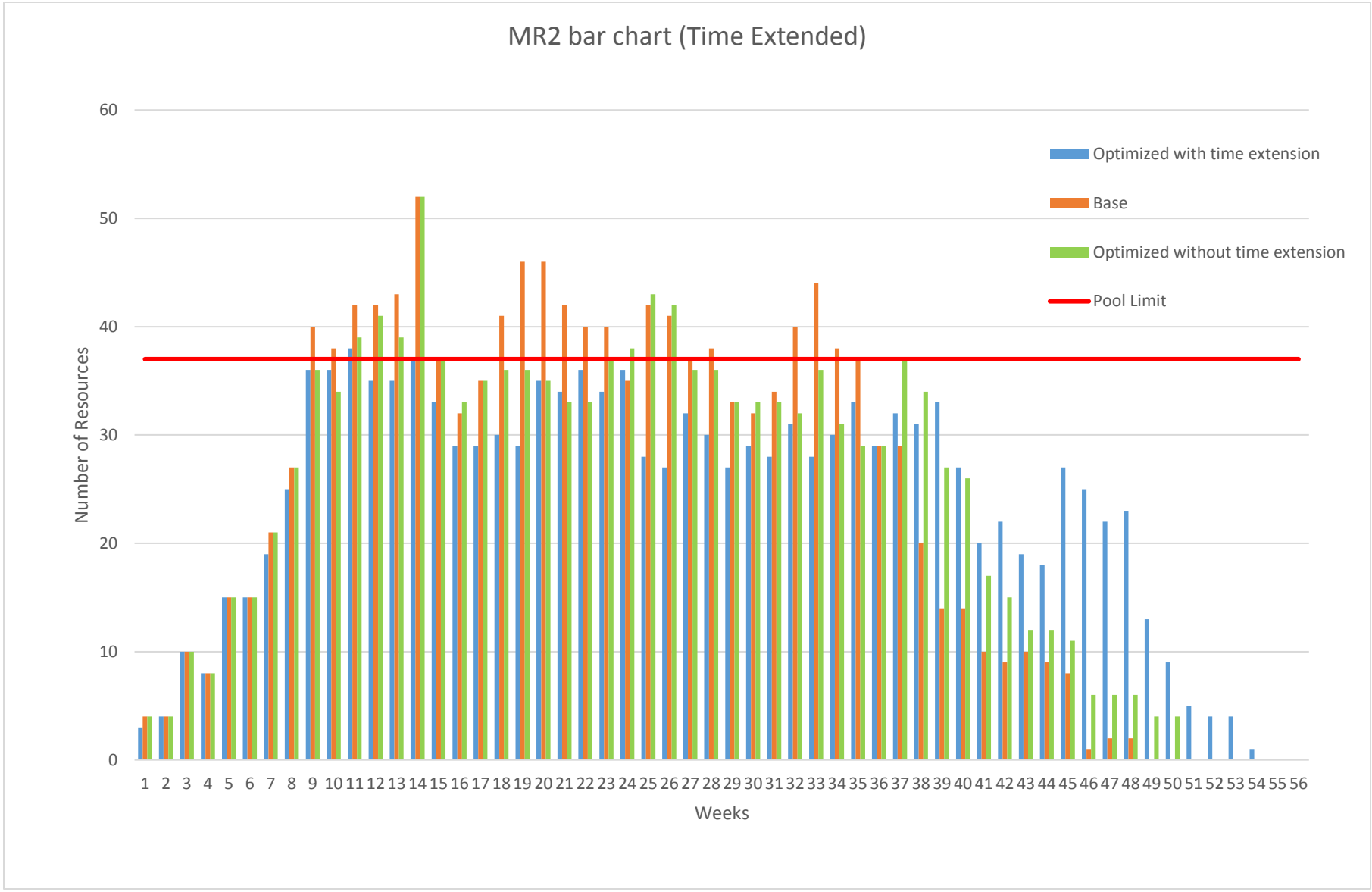


Figure 66 MR2 bar chart (Time Extended)

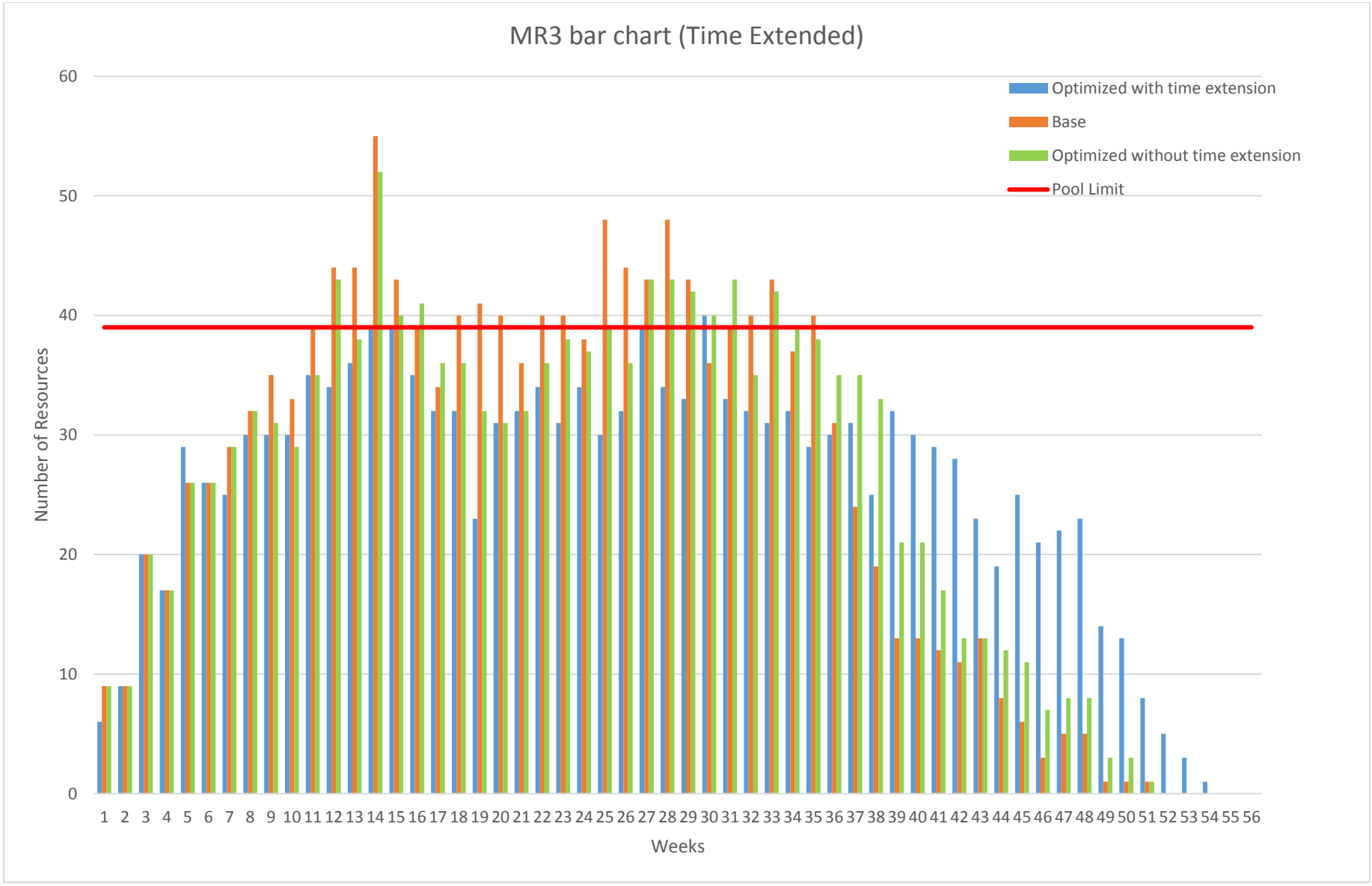


Figure 67 MR3 bar chart (Time Extended)

In conclusion, when an extension of time is allowed, the extra cost of resources will decrease as the projects can spread along a longer period of time allowing the maximum number of resources needed in unit time decrease. The project manager has to put into consideration while scheduling the projects or optimizing the resources the penalty that delay would cause.

Chapter 5: Validation of the Model (Case Study)

5.1 Background

A case study was selected to validate the model. Three projects of residential compounds were selected, that were running at the same time. Nine common resources were selected to optimize the direct cost only.

The resources selected are:

- Carpenter Crew
- Concrete finishers
- Steel Fixers Crew
- Loader
- Bobcat
- Concrete pump
- Column Formwork
- Steel bars reinforcement
- Slab formwork

These resources were selected because they were shared by the three projects and there is limitation in the availability. Table 8 Resources Base Data shows the selected resources base data information:

Maximum number of each resource required throughout all projects durations.

Number of resources available in the pool.

Number of extra resources needed.

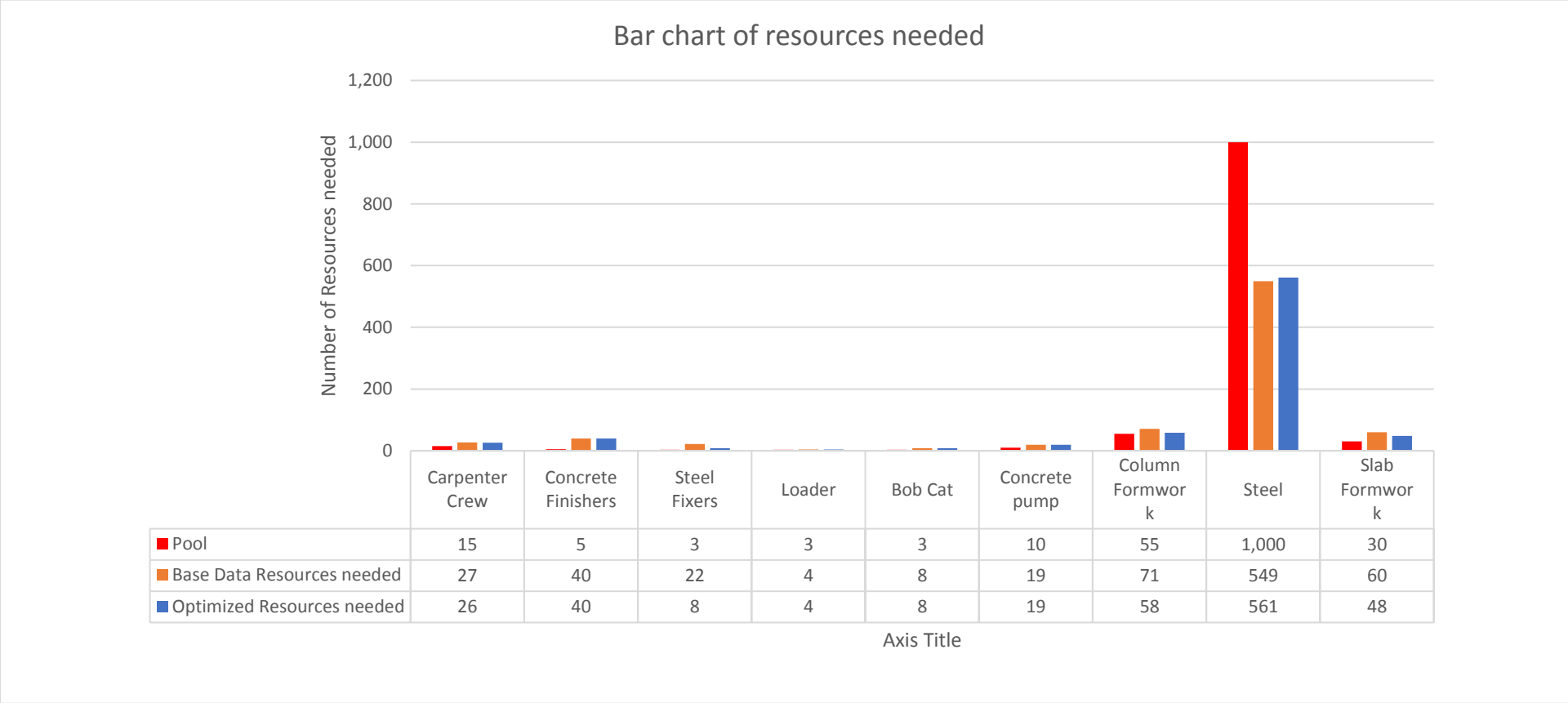
Regular cost of each resource within the pool

Extra cost of each resource out of the pool availability.

Table 8 Resources Base Data

		Required	Pool	Extra	Regular Cost	Extra Cost
Human Resources	Carpenter Crew	27	15	12	450	600
	Concrete Finishers	40	5	35	450	600
	Steel Fixers	22	3	19	450	600
Equipment Resources	Loader	4	3	1	2,154	5,000
	Bob Cat	8	3	5	876	2,500
	Concrete pump	19	10	9	2,000	2,600
Material Resources	Column Formwork	71	55	16	100	300
	Steel	549	1,000	0	9,000	9,000
	Slab Formwork	60	30	30	300	500

5.2 Results and Discussion



	Carpenter Crew	Concrete Finishers	Steel Fixers	Loader	Bob Cat	Concrete pump	Column Formwork	Steel	Slab Formwork
Pool	15	5	3	3	3	10	55	1,000	30
Base Data Resources needed	27	40	22	4	8	19	71	549	60
Optimized Resources needed	26	40	8	4	8	19	58	561	48

Figure 68 Maximum Resources Needed for the Three Projects of Case Study

Figure 68 shows the maximum number of each resource needed before and after optimization. The available pool is also shown in the bar chart.

Figure 69 shows the total cost of extra resources before and after optimization. There was a decrease of more than 50% in the cost of extra resources needed from 216,886 EGP to only 93,046 EGP.

Figure 70 and Figure 71 shows the breakdown of extra cost between the nine resources before and after optimization respectively. Before optimization slab formwork, loader and bob cat costs the most. It was expected that equipment resources would cost the most. But after optimization, the extra costs of all resources were decreased significantly and Bob cats cost the most. Figure 72 shows the detailed extra cost of each resource before and after optimization.

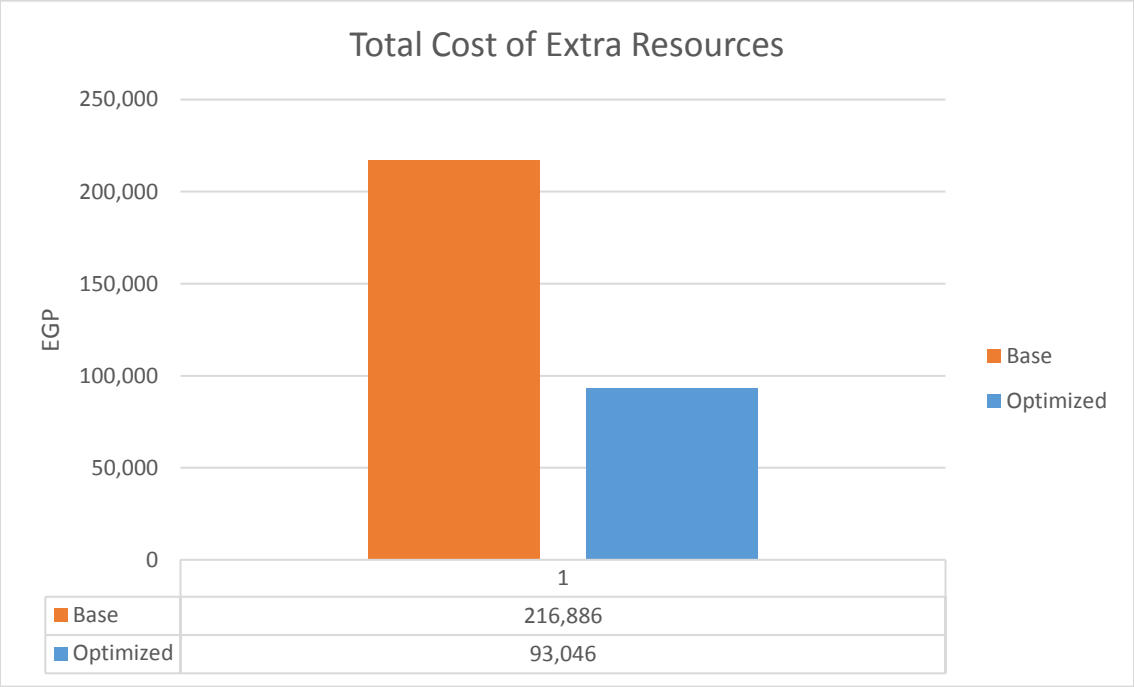


Figure 69 Total Cost of Extra Resources Before and After Optimization

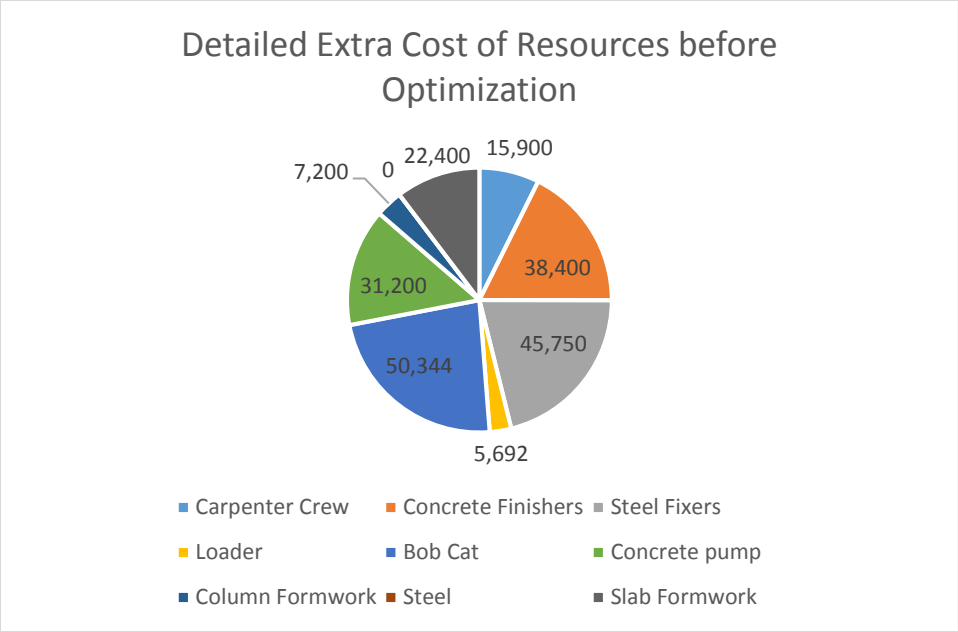


Figure 70 Detailed Extra cost of Resources before Optimization

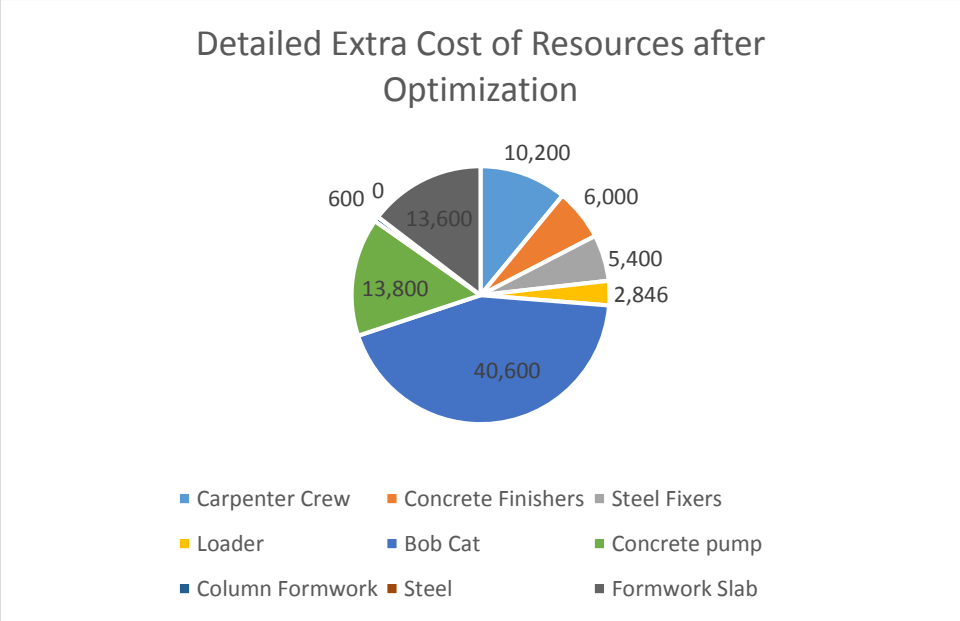


Figure 71 Detailed Extra Cost of Resources after Optimization

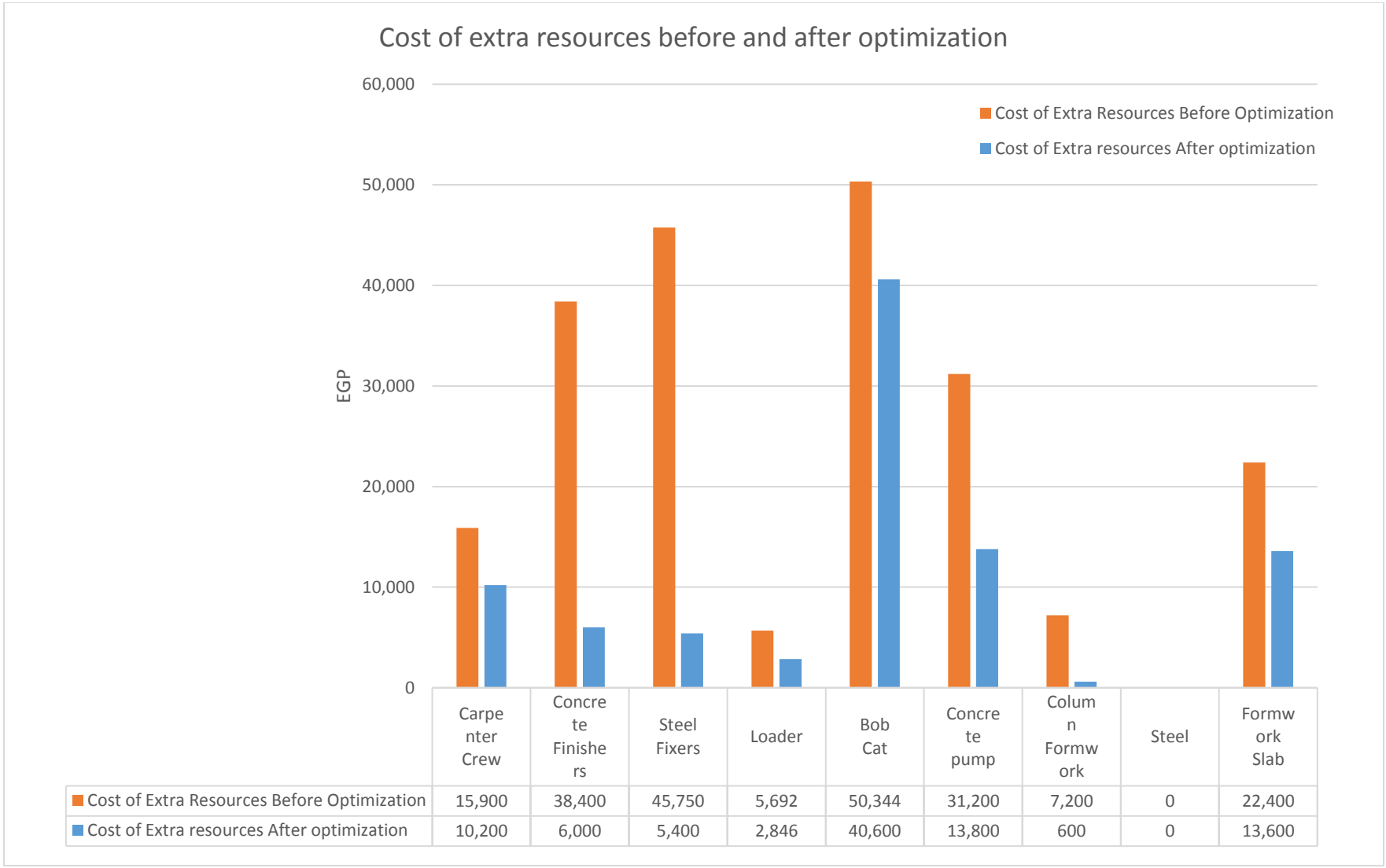


Figure 72 Cost of extra resources Before and After Optimization

Figure 72 shows that cost of extra steel fixers decreased the most after optimization, then follows the concrete finishers. In the equipment, the loader and concrete pump extra cost decreased by more than 50%, while the bob cat decreased the least. In material resources, the column formwork decreased the most then follows the slab formwork. Steel was not exceeding the pool limit already, as it is available and its price is fixed, but steel was chosen as one of the resources as it was common material between all projects and its data was available and would affect the steel fixers in labor resources.

Figure 73-Figure 75 shows the base schedule of the projects 1-3 before optimization respectively. Figure 76-Figure 78 shows the schedules of projects 1-3 respectively after optimization. As it is clear from Figure 73 and Figure 76, there is no delay in project 1's duration. Figure 74 and Figure 77 shows there is no delay in project 2's duration. Figure 75 and Figure 78 shows there is no delay in project 3's duration. All three projects start and end the same time after optimization as before optimization.

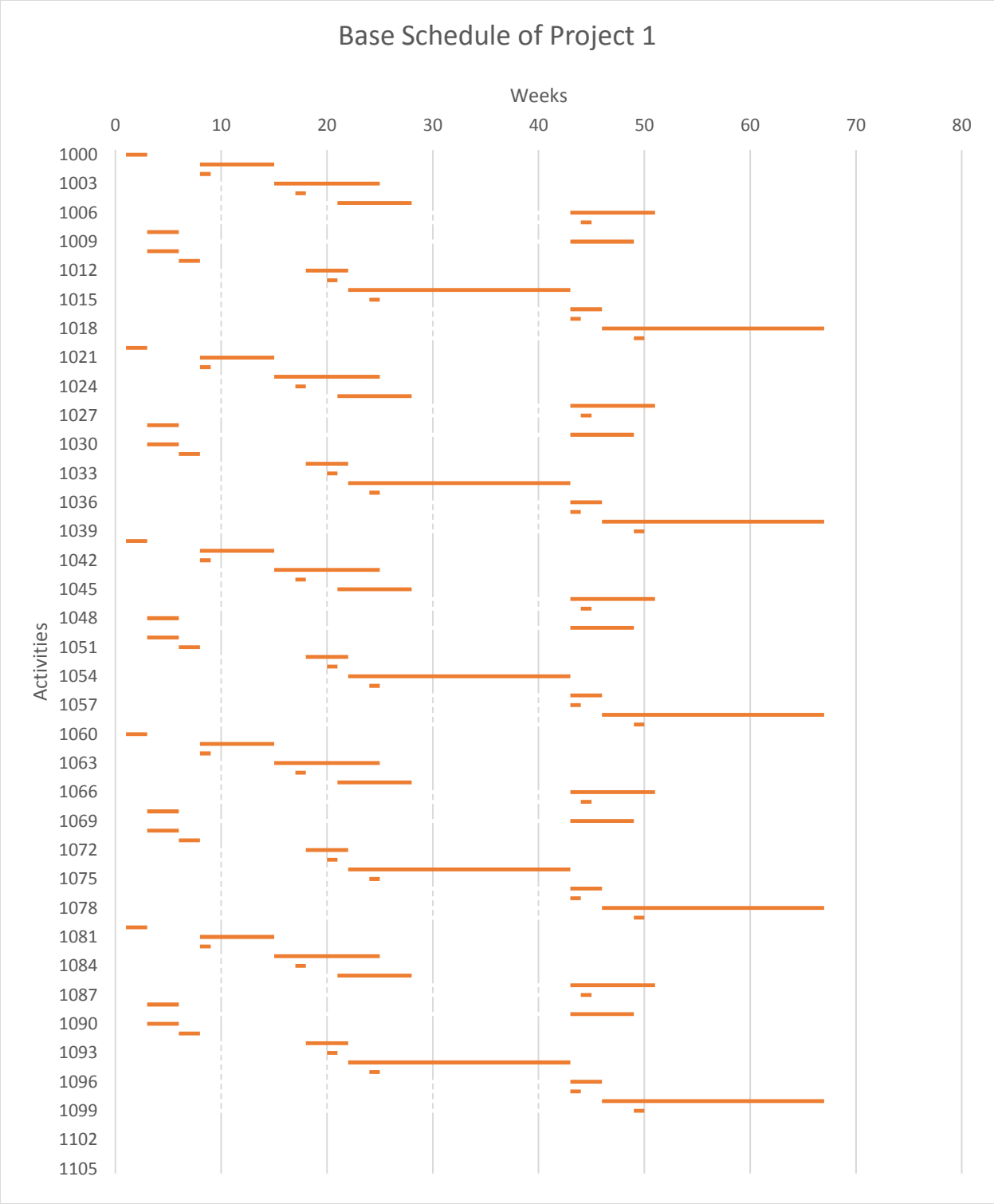


Figure 73 Base Schedule of Project 1

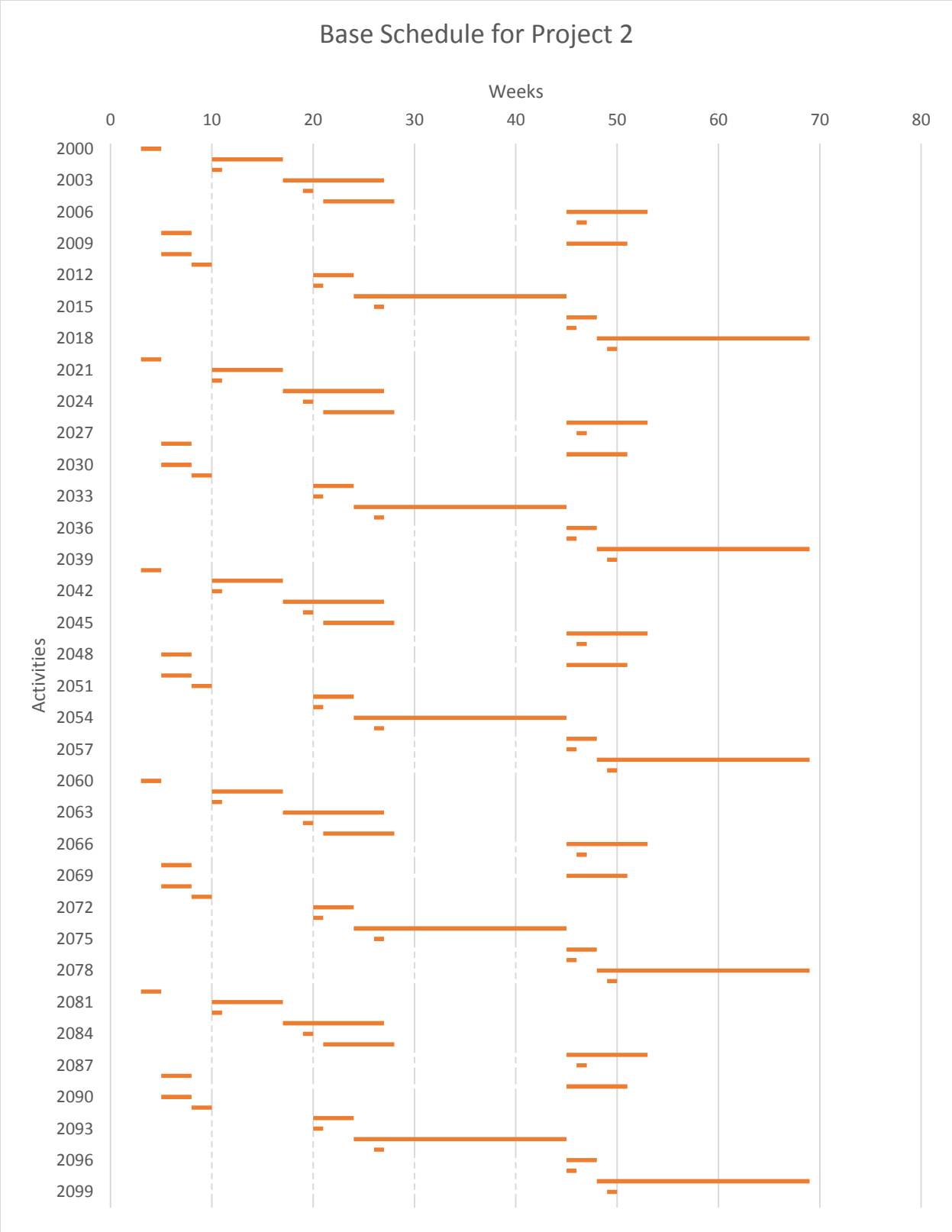


Figure 74 Base Schedule of Project 2

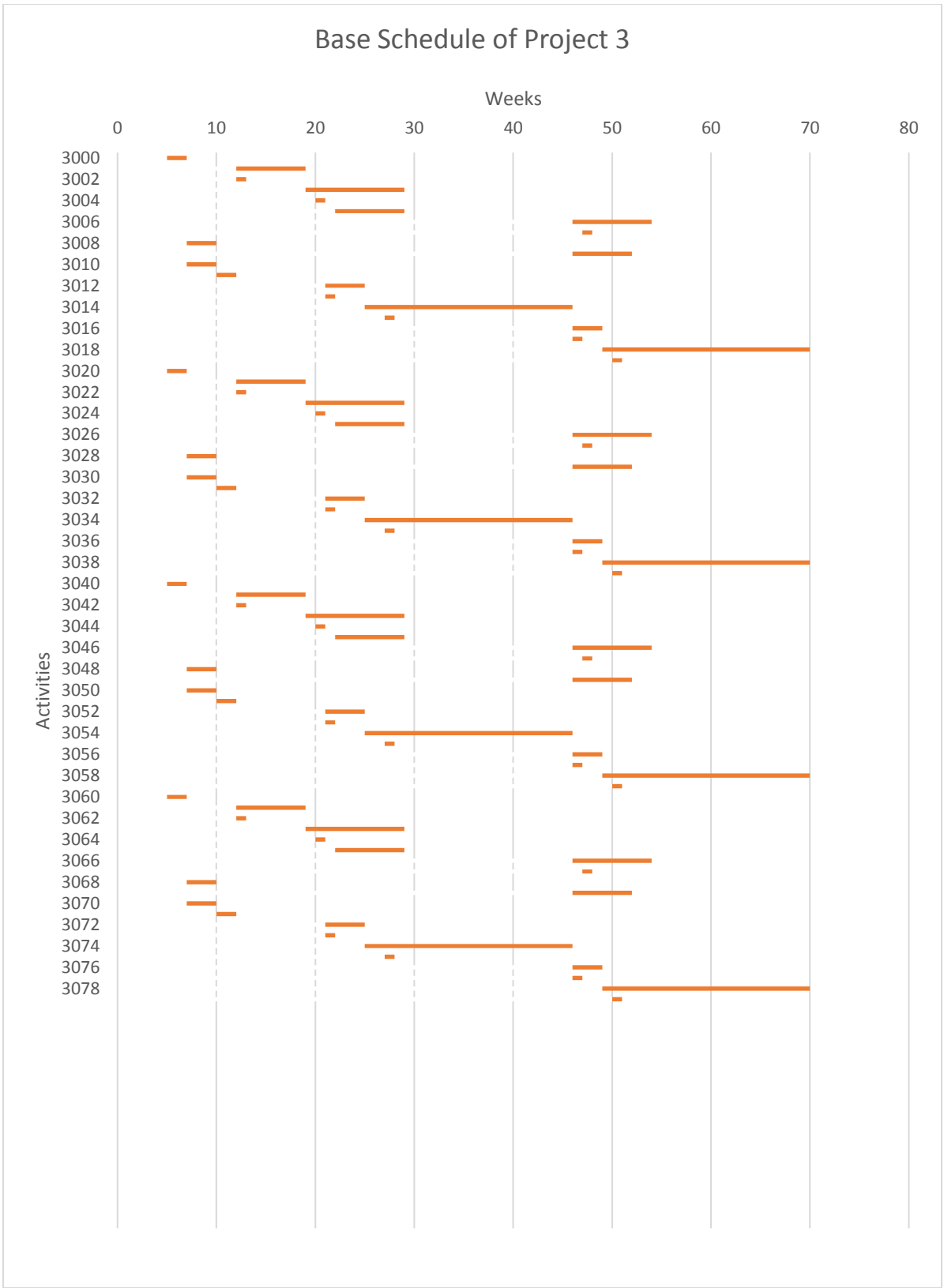


Figure 75 Base Schedule of Project 3

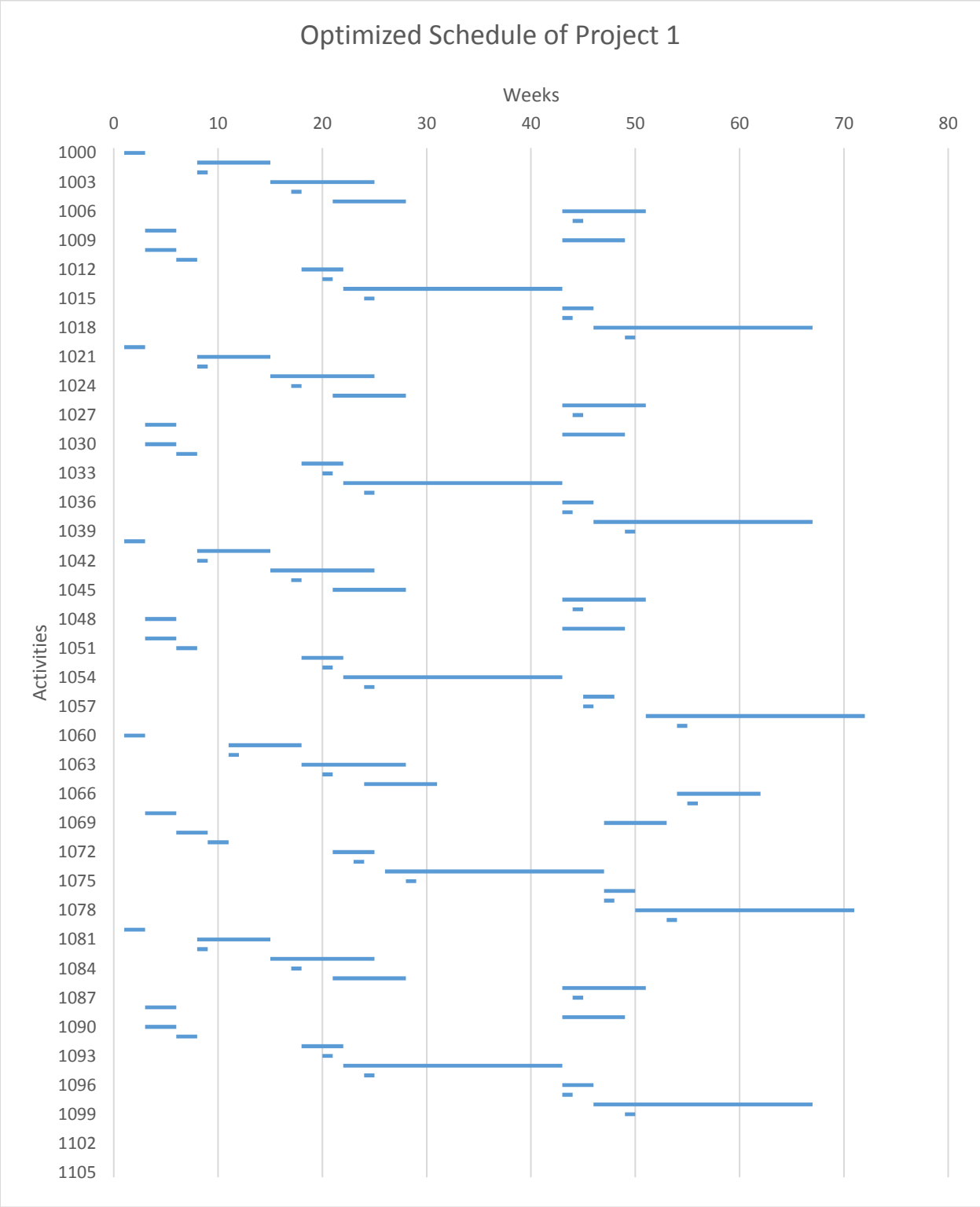


Figure 76 Optimized Schedule of Project 1

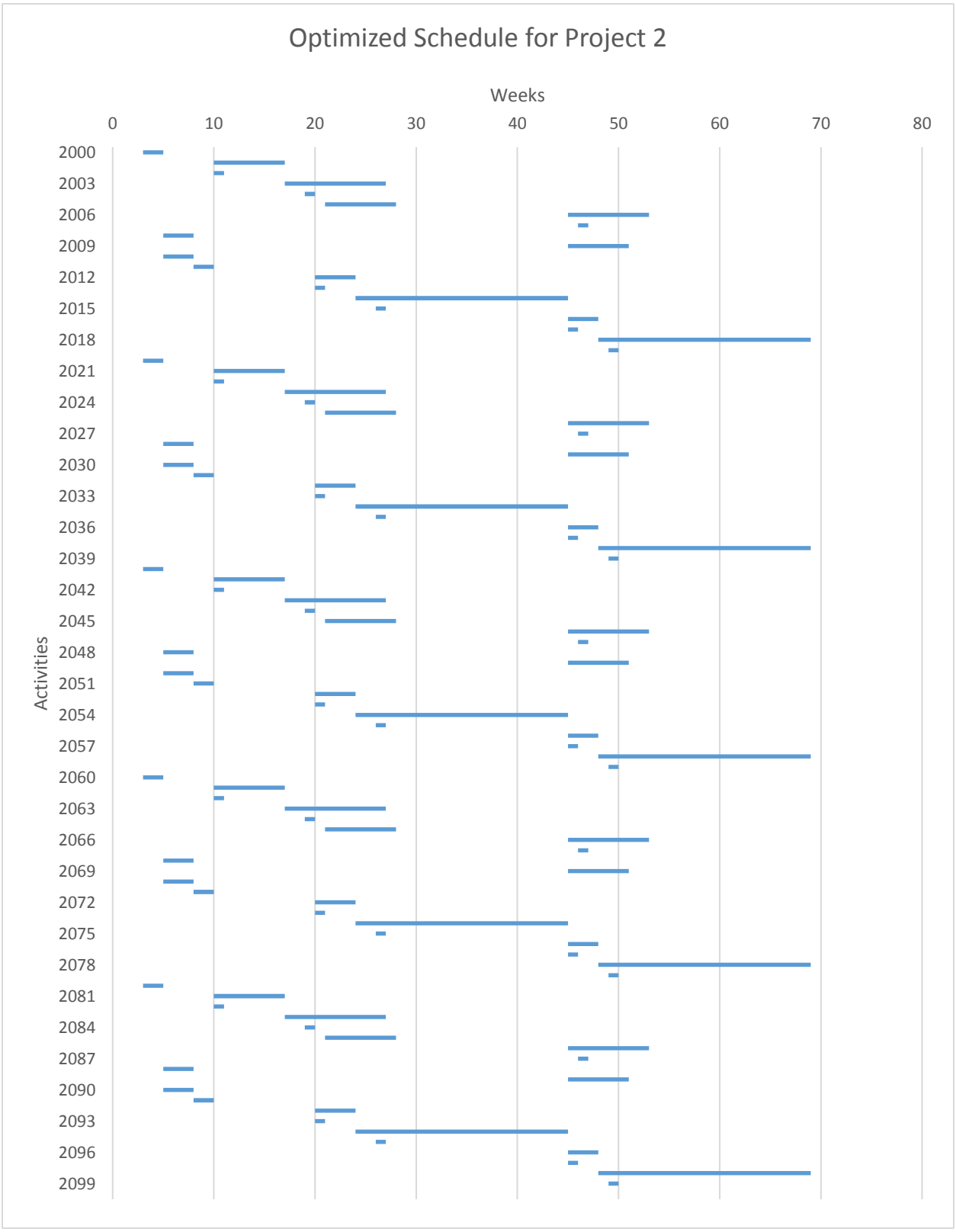


Figure 77 Optimized Schedule of Project 2

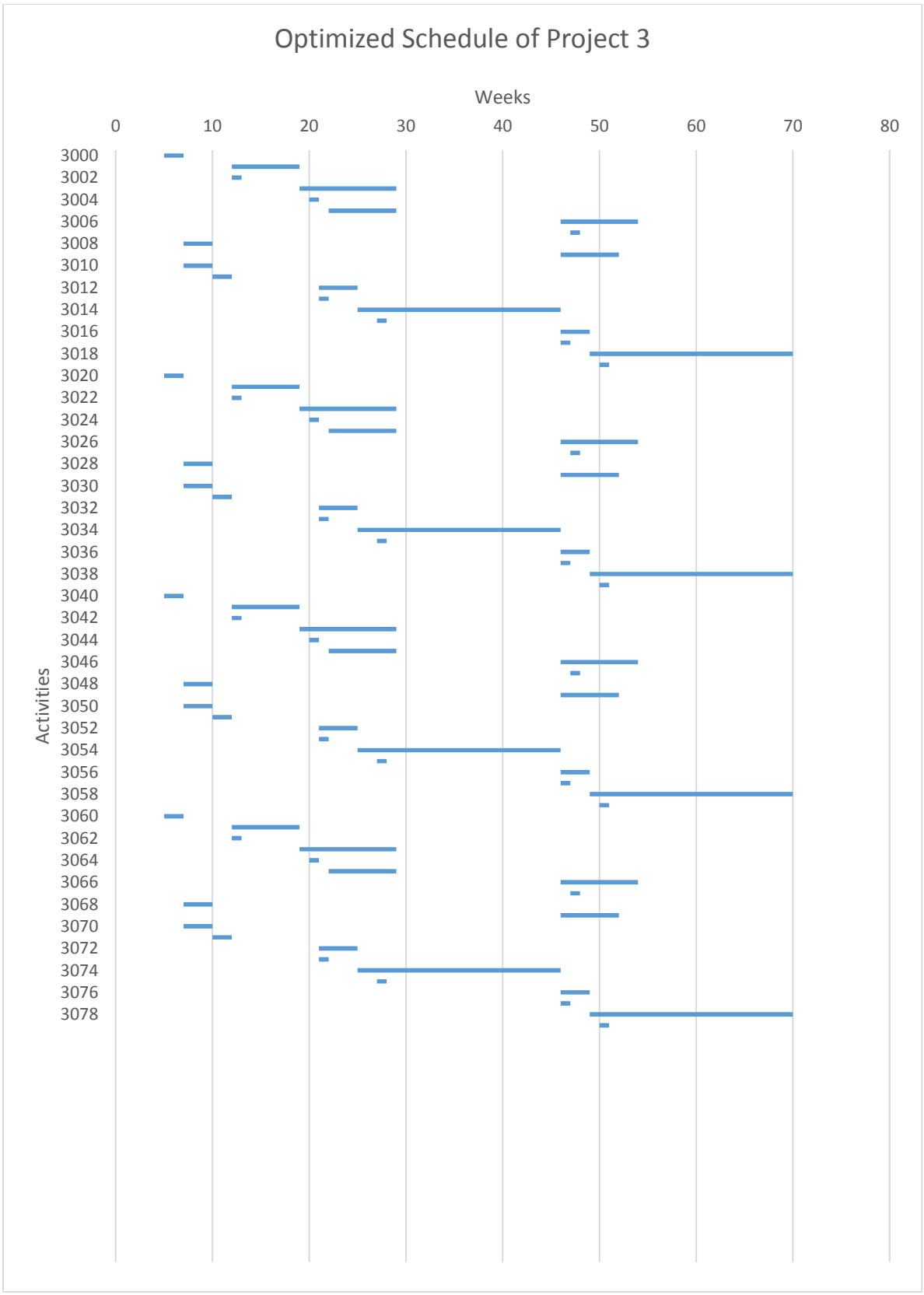


Figure 78 Optimized Schedule of Project 3

Figure 79-Figure 87 shows the daily number of each resource needed before and after optimization, and also the maximum available pool. The model was able to decrease the maximum number of extra resources needed for all resources.

Figure 79 shows the maximum number of carpenter crews needed has been decreased after optimization from 27 carpenter to 24 carpenter; while the pool of available carpenter was only 15. Overall, the cost of extra carpenters needed has decreased by around 30%; as shown in Figure 72.

Figure 80 shows the maximum number of concrete finishers needed has decreased after optimization from 40 concrete finisher to 35 concrete finisher in week# 62; while the pool of available concrete finishers was only 5. Overall, the cost of extra concrete finishers needed has decreased by 84%; as shown in Figure 72.

Figure 81 shows the maximum number of steel fixers needed has decreased after optimization from 22 steel fixers to 7 steel fixers only; while the available pool of steel fixers was only 3. Overall, the cost of extra steel fixers needed has decreased by 88%; as shown in Figure 72.

Figure 82 shows the maximum number of loaders needed has not decreased after optimization and remained 4 Loaders in week# 5, while the available pool was only 3 loaders. Overall, the cost of extra loaders needed has decreased by almost 50%; as shown in Figure 72.

Figure 84 shows the maximum number of bob cats needed has decreased after optimization from 8 bob-cat to 7 bob-cat, while the available pool was only 3 bob-cat. Overall, the cost of extra bob cats needed has decreased about 20%; as shown in Figure 72.

Figure 85 shows the maximum number of concrete pumps needed has decreased after optimization from 19 concrete pump to 16 concrete pump, while the available pool was only 10 concrete pumps. Overall, the cost of extra concrete pumps needed has decreased 66%; as shown in Figure 72.

Figure 85 shows the maximum number of column formwork needed has decreased after optimization from 71 formwork to 58 formwork, while the available pool was only 65 formwork. Overall, the cost of extra column formwork needed has decreased 91%; as shown in Figure 72.

Figure 86 shows the maximum number of steel needed has not changed as it is already under the pool limit; the cost of extra steel needed is zero before and after optimization; as shown in Figure 72.

Figure 87 shows the maximum number of slab formwork needed has decreased after optimization from 60 formwork to 44 formwork, while the available pool was only 30 formwork. Overall, the cost of extra slab formwork needed has decreased by almost 50%; as shown in Figure 72.

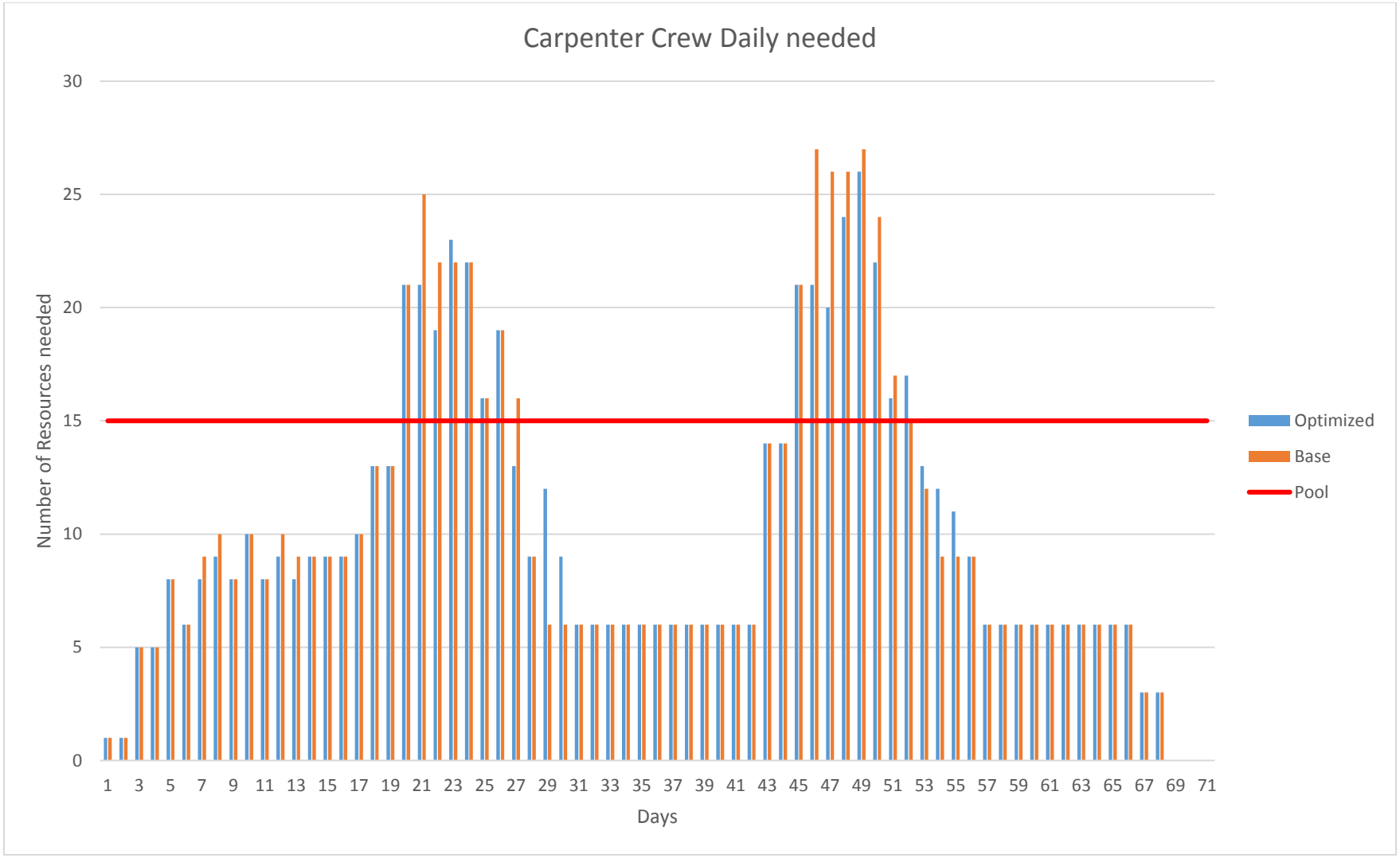


Figure 79 Carpenter Crew Daily needed

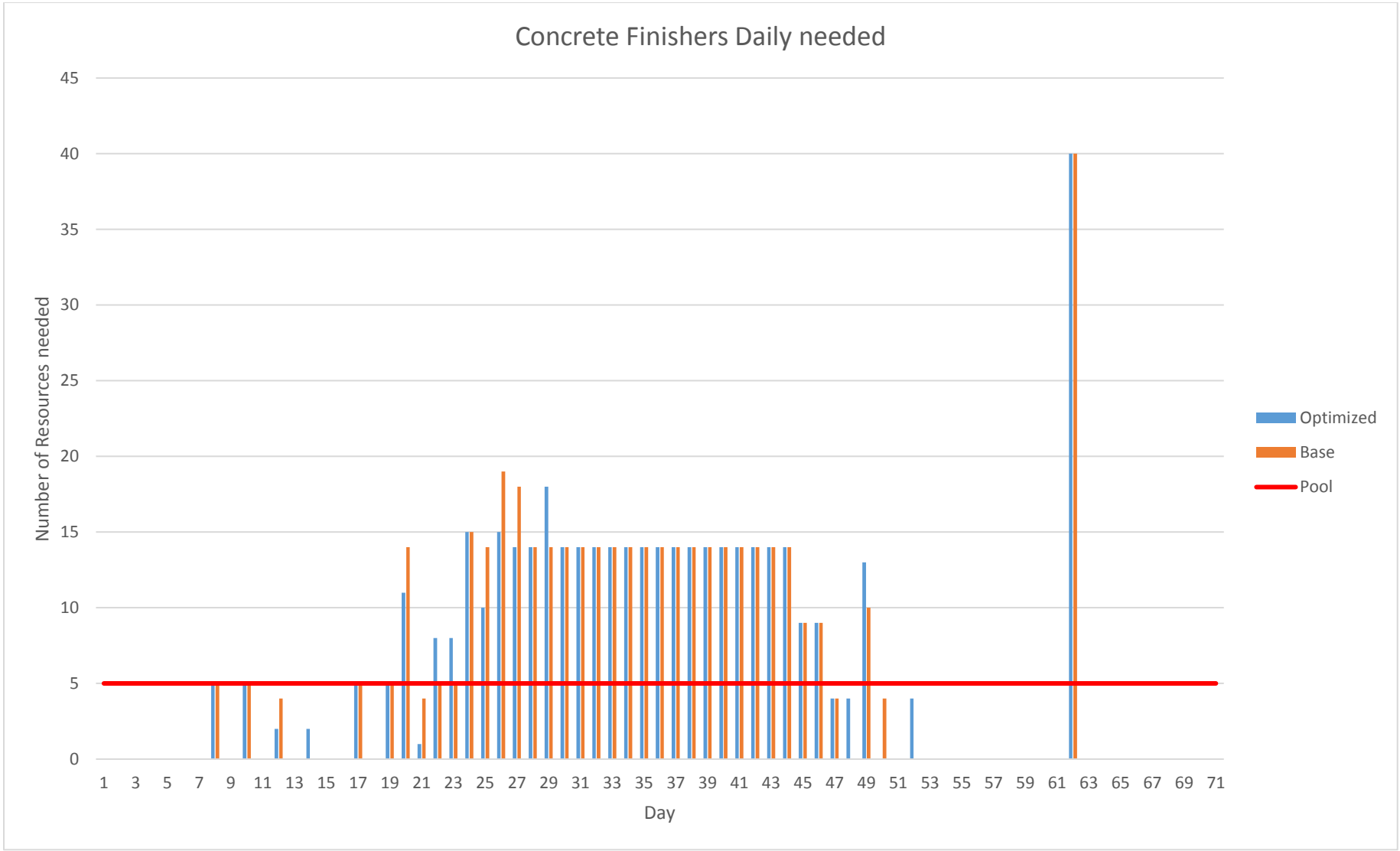


Figure 80 Concrete Finishers Daily needed

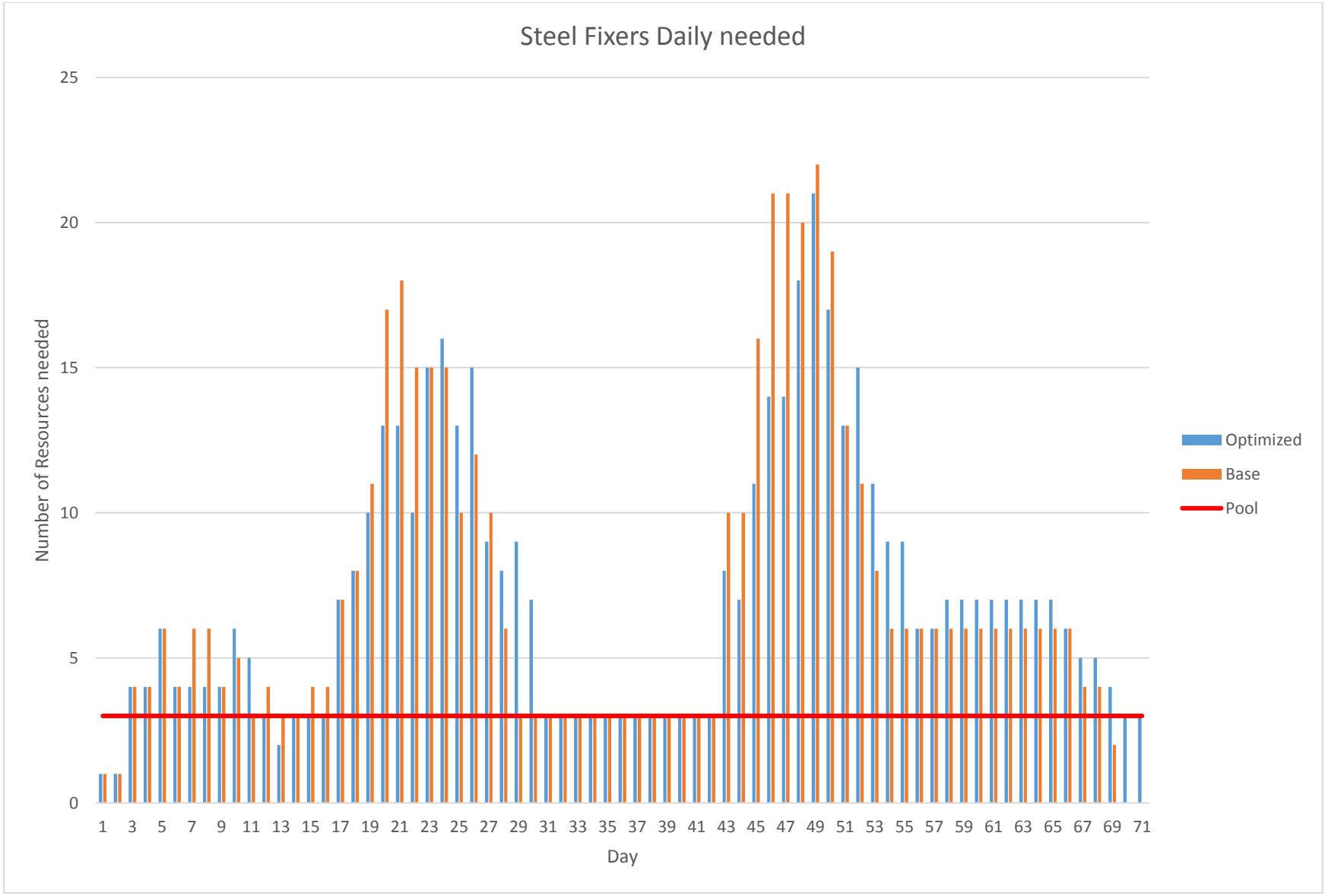


Figure 81 steel Fixers Daily needed

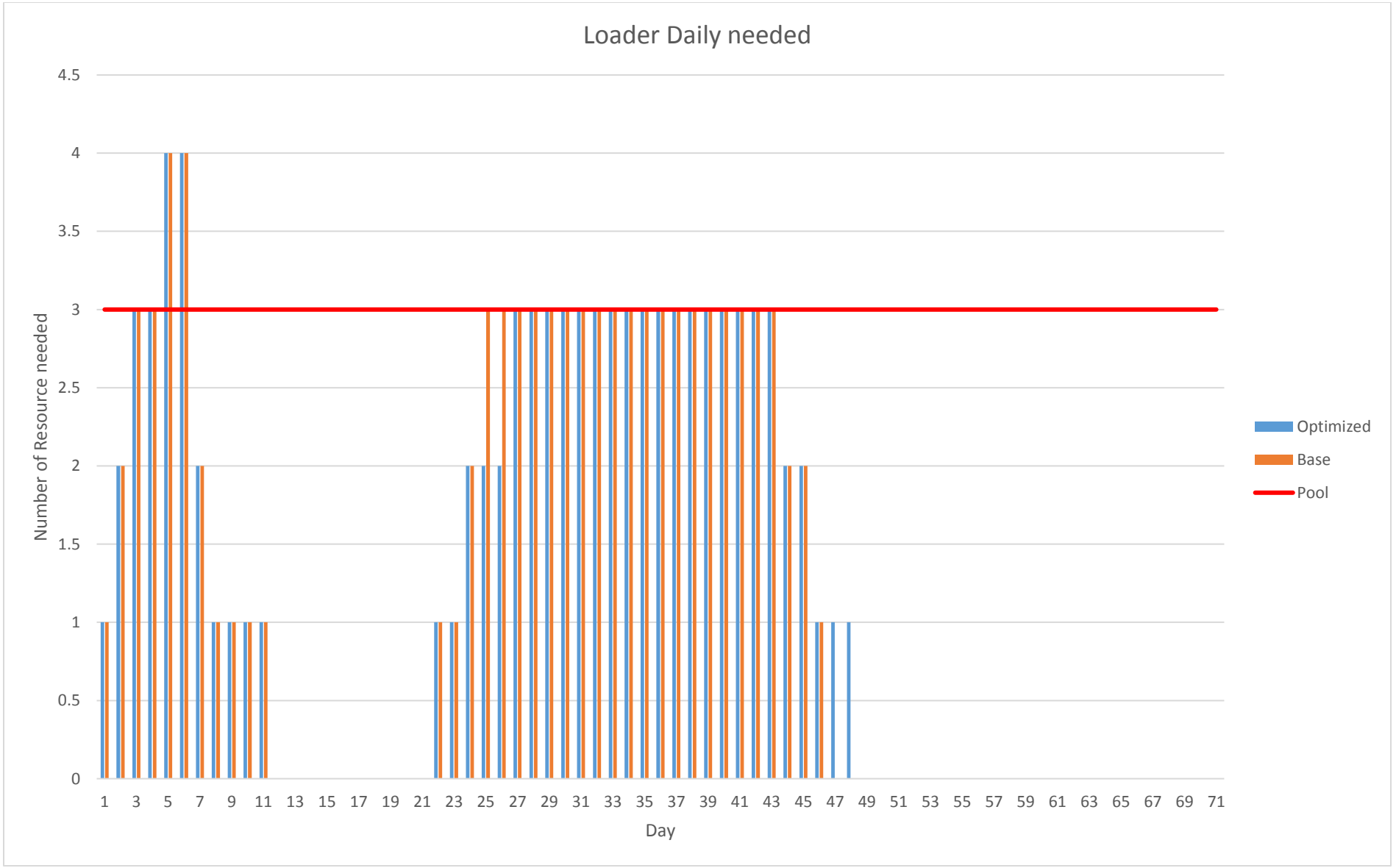


Figure 82 Loaders Daily needed

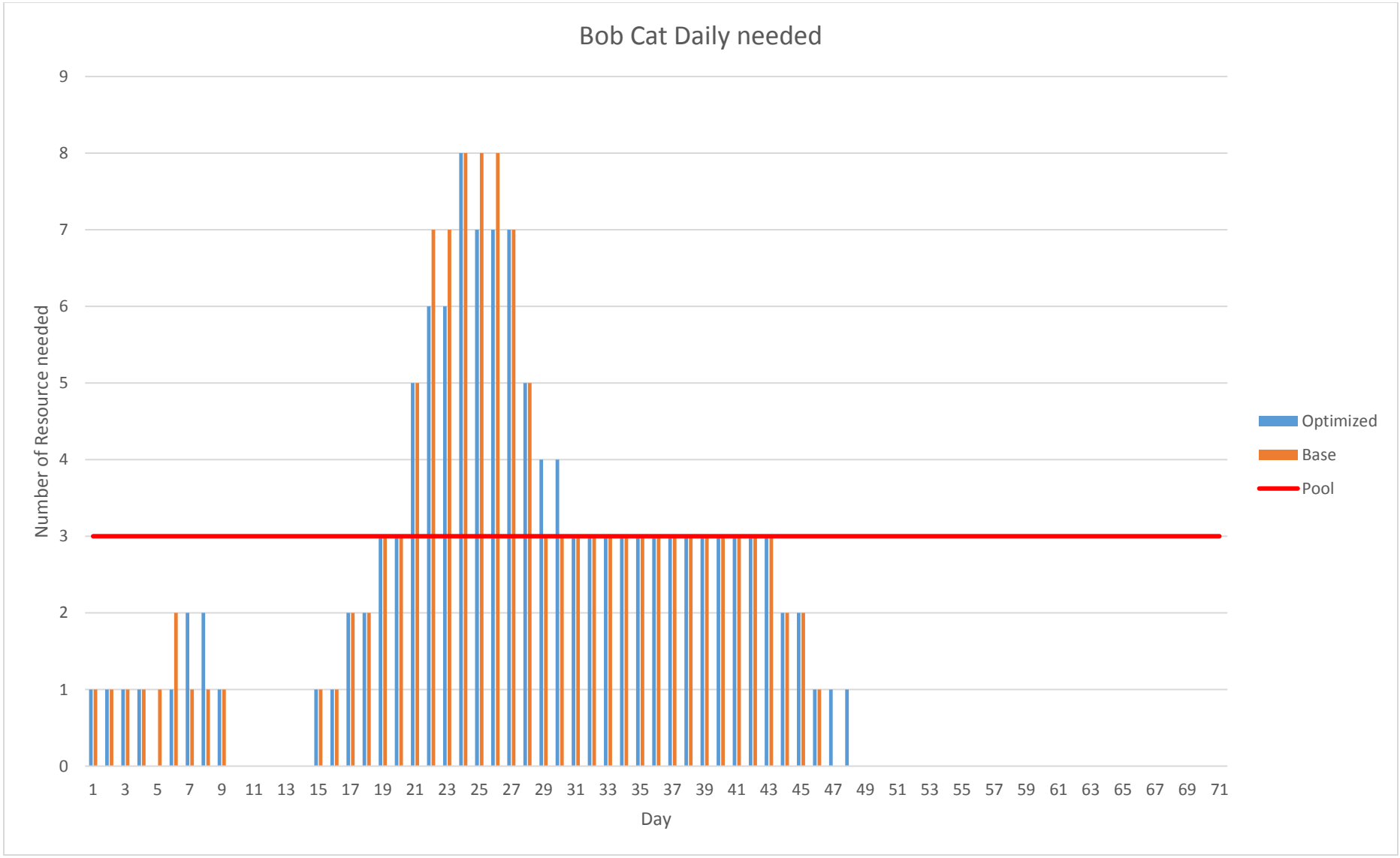


Figure 83 Bob cat Daily needed

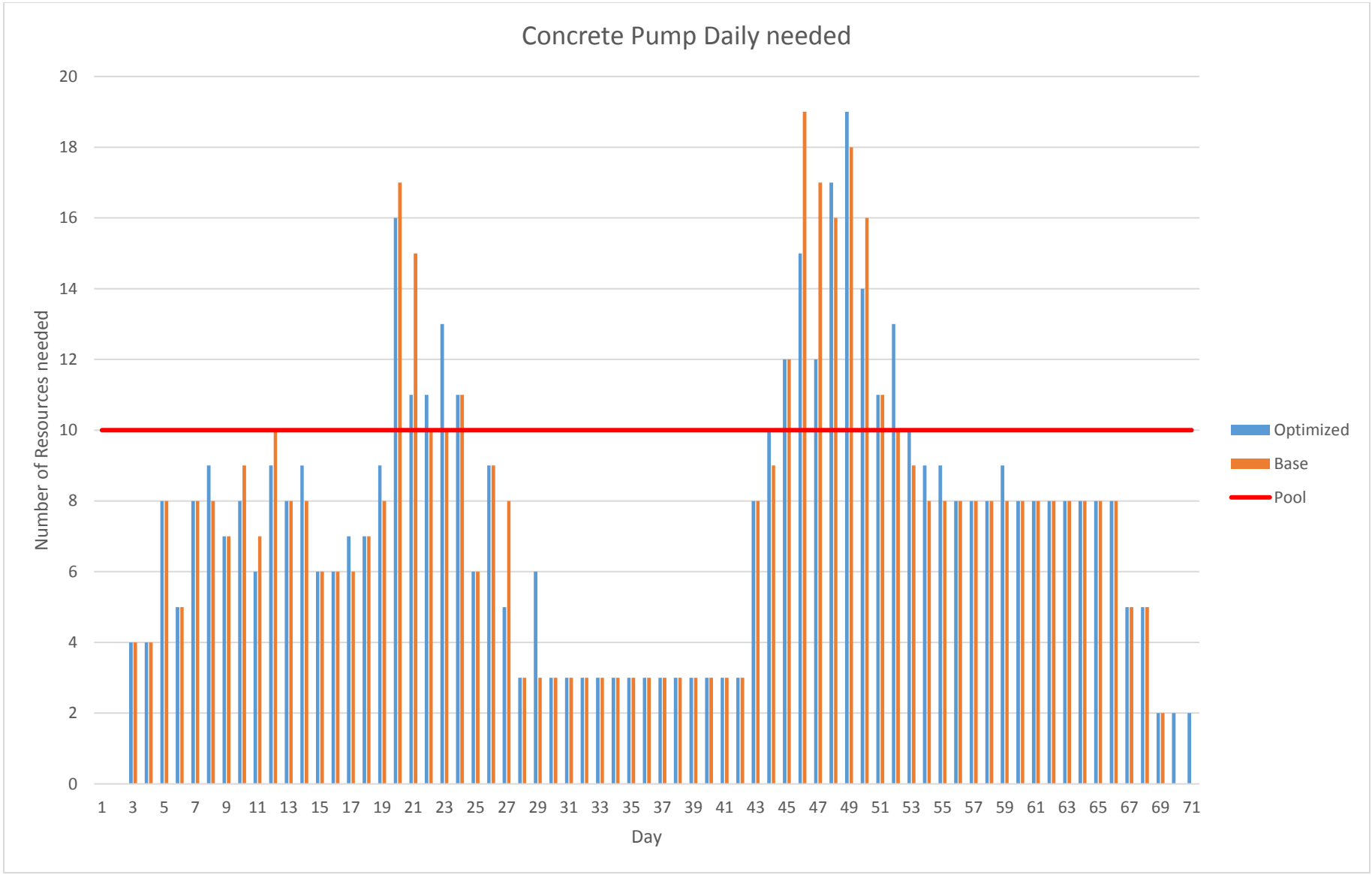


Figure 84 Concrete Pump Daily needed

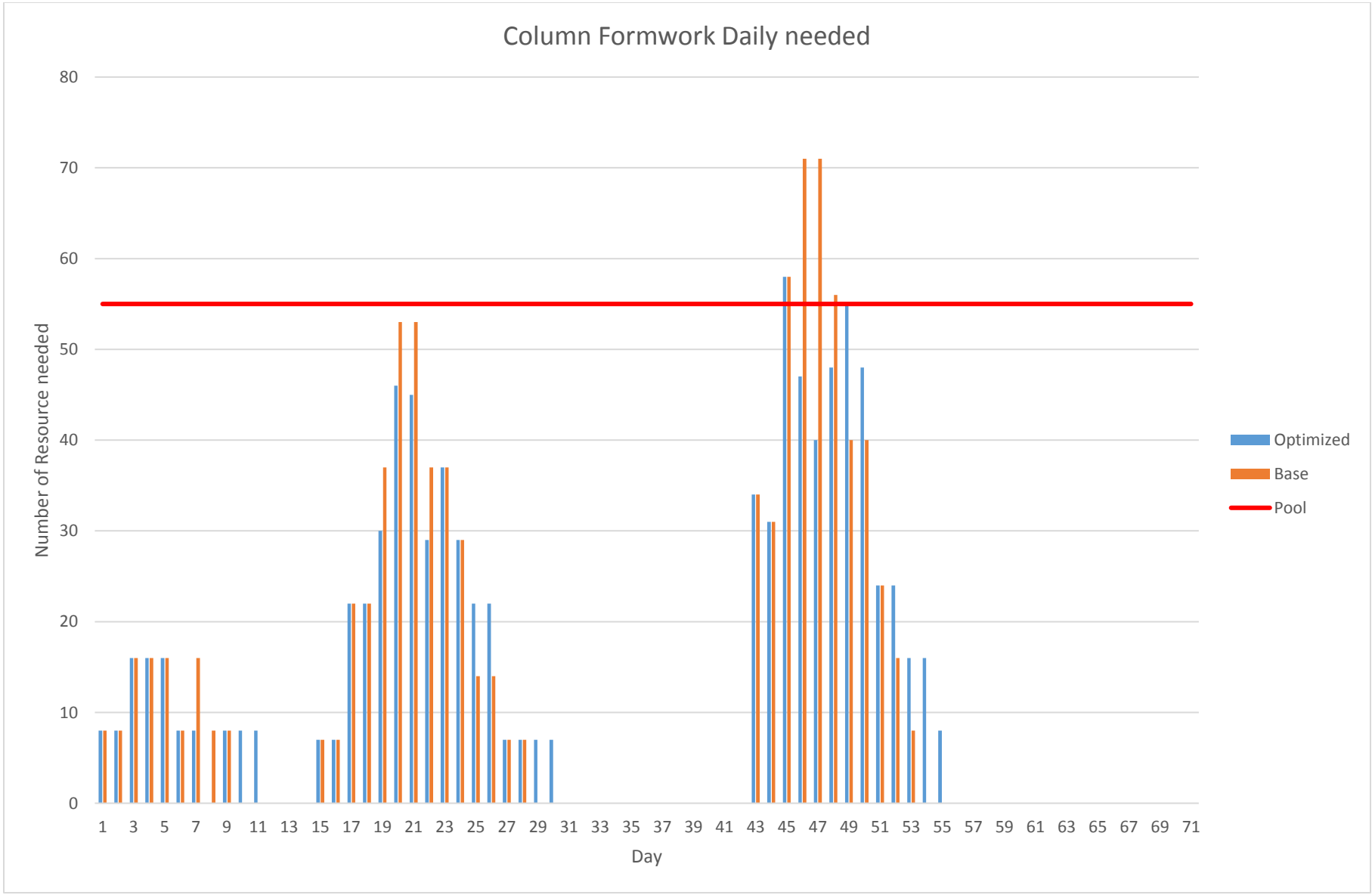


Figure 85 Column Formwork Daily needed

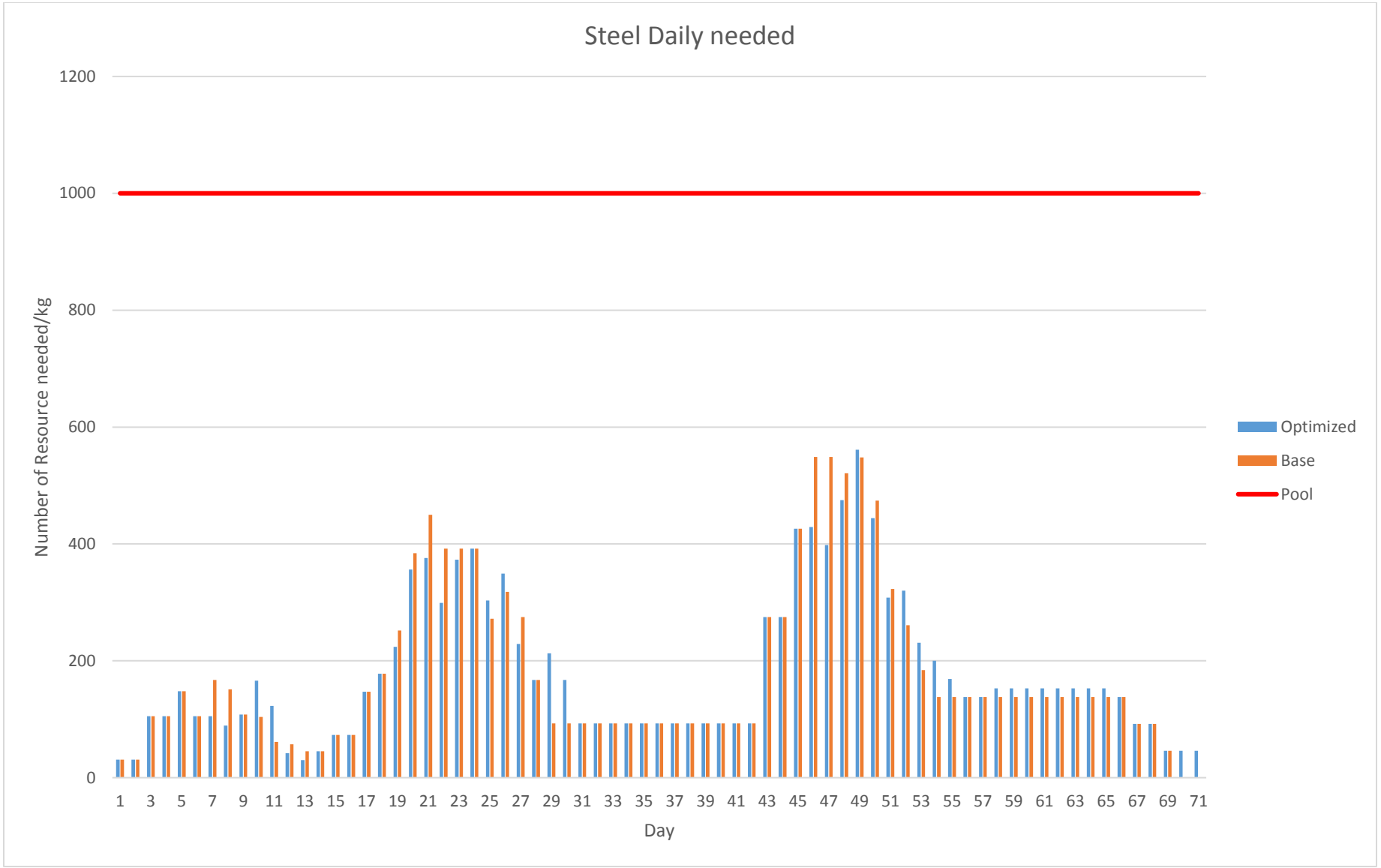


Figure 86 Steel Daily needed

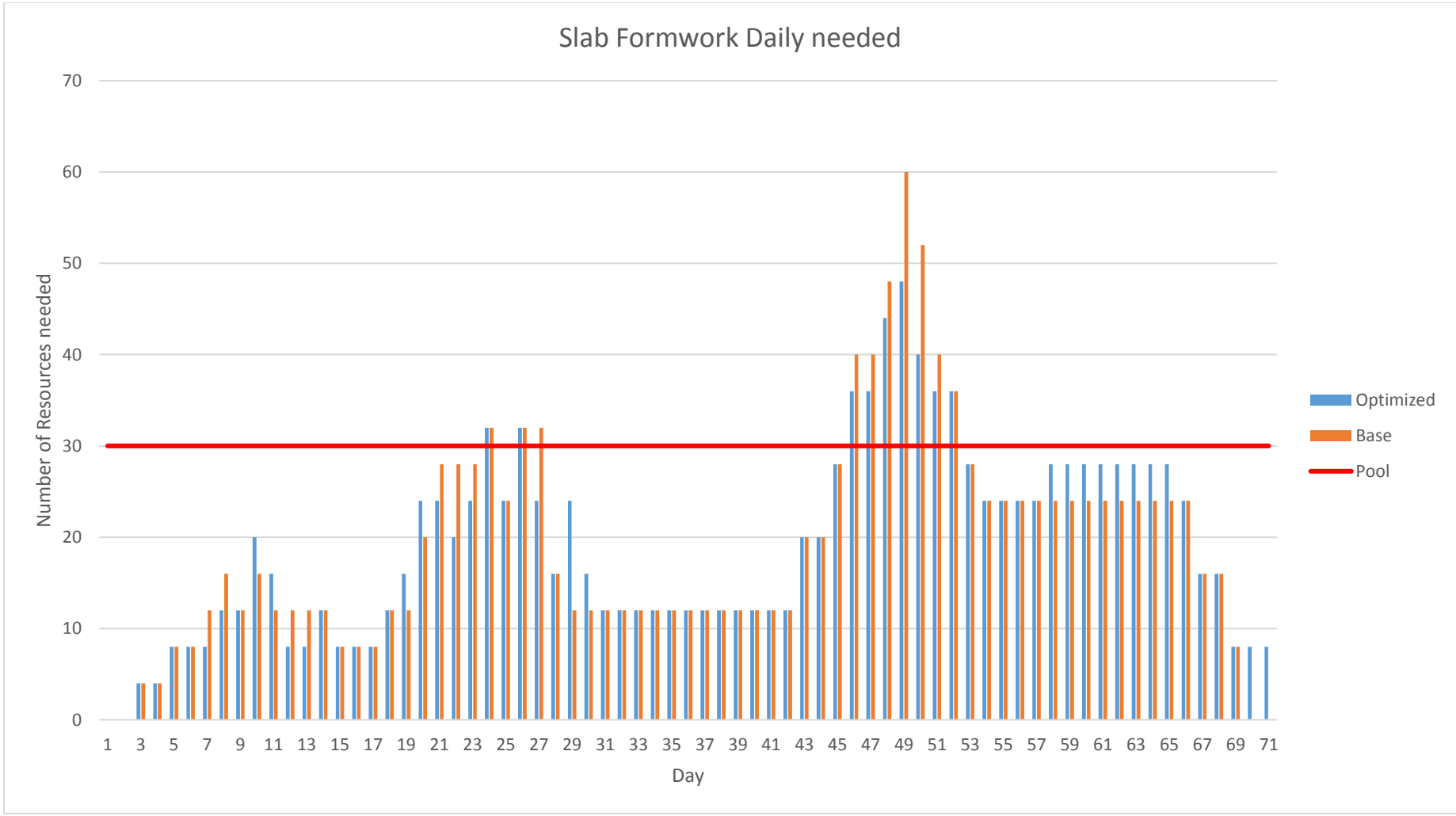


Figure 87 Slab Formwork Daily needed

Chapter 6: Conclusion and Recommendations

6.1 Conclusion

Most of the studied addressed earlier, was focused on allocating the resources not taking into consideration the cost of each resource especially when allocating multiple resources. The gap in the literature was found and the model generated from this thesis was able to optimize the cost of nine resources not only for one project but to three projects running at the same time. The model can be used by any project manager or multiple project manager, using just Excel software and without the need to purchase any other software. This model will help not only contractors but also consultants, to be able to utilize their resources well for the while company's portfolio, and at the same time save money. This model is adjustable to any projects, and any resource number. The model can optimize a single resource only for several projects, multiple resources for single projects, or multiple resources if several projects. For this model, the resources that were optimized were divided into 3 groups:

- Labor (3 different types of labors)
- Equipment (3 different types of equipment)
- Materials (3 different types of materials)

6.2 Research Findings

The optimization was done to decrease the cost of any extra resources needed than the available pool, so the model utilizes the available resources in the most efficient manner.

The model was tested on different scenarios, and the pool of resources was reduced by 10%, 15%, 20%, 25% and 30%:

- When the model was tested on a single project only, the cost of extra resources was eliminated up to 25% less in the pool. When the pool of resources was decreased by 30%, more than 99% decrease in the cost of extra resources.
- When the model was tested on optimizing a single resource for three projects running concurrently, the cost of extra resources was eliminated up to 30% less in the pool.
- When the model was tested on 2 projects and multiple resources, the cost was eliminated when the pool of available resources was reduced by 10%, 15% and 20%. But when the pool was reduced by 25% and 30% the extra cost of resources was reduced by almost 90%.
- When the model was tested on three projects and multiple resources without any extension of time, the cost of extra resources was almost eliminated after optimization when the pool of available resources was reduced by 10% and 15%. But, when the pool was reduced by 20%, the extra cost of resources was decreased by 90% after optimization and when the pool was reduced by 25% and 30%, the decrease in extra cost of resources was more than 50%.
- When the model was tested on three projects and multiple resources but allowing extension of time by 5%, 7% and 10% the results were much better than keeping the deadline of the projects. The cost of extra resources was reduced by:
    - 88% when 5% extension of time was allowed,
    - 96% when 7% extension of time was allowed,
    - 98% when 105 extension of time was allowed.

A case study was selected to test the model on real project's data. The extra cost of resources was reduced by more than 50%.

From all the above we can conclude the following:

- Model was able to reduce the cost of extra resources in all different scenarios and case study of a real project.
- Model gave better results when tested on a single project with multiple resources than multiple projects with multiple resources.
- Model gave good results when tested on optimizing a single resource of multiple projects. The project manager might use it when a certain resource is of great value.
- Model gave better results when tested on multiple projects with multiple resources but allowing extension of time. The project manager has to keep in mind the penalty of any delay, or he may use the model at the beginning of the project to eliminate any extra cost of resources.
- The model is user friendly, and easy to use it to save time and money.

6.3 Recommendations

Despite this model was able to fill a gap in the literature, there is still room for development and improvement for more efficient and accurate results. Below is a list of recommendations for future researchers:

- Build up a model that would accommodate all the resources in the projects.
- Expand the model to be able to optimize more than three projects.
- Take into consideration the fluctuation in the resources, and the money wasted from un-used resources.

- Investigate various optimization techniques other than genetic algorithm.
- Build up a model that would allow change in the number of resources throughout the activity period.
- Allow variation of the pool of available resources throughout the project.

Chapter 7: References

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