CME Masters Thesis

Can the Mitigation Planner contribute to keeping cost of organizing the Olympic games within limits?

Written by: Omar Doughan (4618165)
Presented to: *dr. ir. L.A. van Gunsteren*
dr. ir. J.G. Verlaan
dr. ir. P.H.A.J.M. van Gelder

Abstract

This report is part of the course CME 2000 – Graduation Thesis. The research entails the study of the construction of the Olympic village for the 2016 Rio Olympics. As Masters Thesis projects are meant to bring something new to the table, this research intends to show how a tool called the "Mitigation Planner" can help in organizing a mega project such as the Olympic games.

Through an interview with previous chairman of the Dutch Olympic Committee, Mr. Mickey Huibregsten, it was realized that the IOC has no tools that help it assure that construction of venues or even Olympic villages are completed on time, he also insisted that the IOC "*should invest in R&D efforts to develop tools, which are made available for any candidate for an event*". Tools, that with the help of previous experience and knowledge of troubled Olympic games, can assist current and future host countries avoid previous mistakes and keep construction costs and delays under control irrespective of the level of skill in that host country.

The report will study the construction schedule of the 2016 Rio Olympic village, along with the costs and payment scheme, which with the help of the Mitigation Planner will drastically improve the probability of completion from 0.11% to at least 51.11%, while also keeping the overall payment scheme spread out over the entire project cycle rather than having a large spike in costs at the end to make up for delayed activities.

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Abbreviations

APO – Autoridade Publica Olimpica (Olympic Public Authority)

CEO – Chief Executive Officer

CPM – Critical Path Method

IBC – International Broadcast Center

IOC – International Olympic Committee

IPC – International Paralympic Committee

MPC – Main Press Center

NOC – National Olympic Comittee

NSF – National Sports Federation

PDM – Precedence Diagram Method

PERT – Program Evaluation Review Technique

PPP – Public-Private Partnership

WBS – Work Break-down Structure

1. Introduction

Hosting the Olympic Games is notoriously known for overrunning the initial budget by considerable amounts. The main goal of organizing the Olympics is to have everything ready to go by the time the Olympics start. This gives organizers about a seven-year time period, from winning the tender to host the games, till opening day. Typically, when given a span of seven years, the feeling of having enough time to complete the required construction works exists, which eventually leads to expensive additional efforts to catch up with wasted time later down the path. That is partly of what happened to the Rio Olympics, leading it to be labeled as "the worst Olympics preparations ever" by John Coates, International Olympic Committee (IOC) vice-president at the time. Before getting into detail on what happened with the Rio Olympics, first this chapter will give a brief description of the history of the Olympics with examples of past problems such as at the Montreal Olympics of 1976. With that in mind, the next sections of this chapter will describe the problem of organizing the Olympics and the objective of this research. Rounding up the chapter will be the presentation of the research question along with the research methodology.

1.1 Olympic Games Organization History

Given the reputation of hosting the Olympics and the vast amount of resources and costs that go into its organization, it is of vital importance to study these mega-projects to better understand how they work and how to best tackle the problems faced. As a start, in July 2016, Professor Bent Flyvbjerg from the Said Business School, at the University of Oxford conducted a research about the costs and more importantly the cost overruns at the Olympic games. The research studied a number of Olympic events spanning over a period of 56 years, from 1960-2016, including only sports related costs. As established by the IOC, there are three cost categories when hosting the games (Flyvbjerg, Stewart & Budzier, 2016):

1. *Operational Costs*: These costs are incurred by the organizing committee for the purpose of "Staging" the games. These costs entail technology, transportation, workforce and administration cost, among other.
2. *Direct Capital Costs*: These costs are incurred by the host city/country or private investors to construct the competition venues, the Olympic village and all the broadcasting and media centers.
3. *Indirect Capital Costs*: These costs entail the construction of roads, railways and airport infrastructure.

The operational costs and the direct capital costs are the costs that constitute the sports related costs specified earlier by Flyvbjerg. In this research Flyvbjerg studied all the Olympics, summer and winter, between the specified period and came to the conclusion that the average cost overruns in organizing the Olympics is a staggering 156%, with 176% cost overruns for summer games and 142% cost overrun in winter games. By far the worst cost overrun occurred in 1976, in the Montreal Olympics, which was a cost overrun of 720%! To learn more about why the cost overruns for the 1976 Montreal Olympics was so high a further research was considered. This research was conducted at the Cleveland State University and titled "1976 Montreal Olympics: Case study of Project Management Failure". Directly in the introduction it is made clear what the problem was, or at least one of the problems. On May 12, 1970 Montreal was awarded the 1976 Olympic games with an initial plan and cost estimate of $124 million by Montreal Mayor Jean Drapeau. After winning the bid to host the games "*for the next few years, very little was done. The original plan was scrapped… a new plan was laid out in a press conference on April 6, 1972. Almost 2 years of preparation time had been wasted…in November 1972, Drapeua gave a figure of $310 million as the total projected cost of the Olympic games" (*Patel, Bosela & Delatte, 2013*).* Not only did the cost estimate go from $124 million to $310 million in 2 years, a rise of 250%, but also those 2 years were lost as construction time or at least planning, as nothing was done in that period.

1.2 Problem

Normally in construction projects the biggest concern for the client is the cost overrun, but that is not the case for the Olympic games, despite the high cost overruns shown by Professors Flyvbjerg's study. The main concern for the Olympics is having the venues ready to go by the time the event starts. A country winning the bid to organize the Olympics has roughly seven years available to prepare for the event. Usually, in the first few years the feeling prevails of having plenty of time to complete the required construction works. As a result, expensive extra efforts are needed to catch up for the wasted time at the beginning. So is the case for most Olympic games, with Montreal 1976 being a prime example.

> "*The planning started 2 years too late, and scheduling fell apart because it was physically impossible to accommodate all the construction activities on the project site… Double crews, double shifts, and overtime were used to attempt to increase productivity but because of congestion, the increase in productivity was slight*" (Patel, Bosela & Delatte, 2013)

Flyvbjerg said it best in his research on costs and costs overruns in the Olympics:

> "*The high cost overrun for the games may be related to the fixed deadline for project delivery: the opening date cannot be moved. Therefore, when problems arise there can be no trade-off between schedule and cost, as is common for other megaprojects. All managers can do at the Olympics is throw more money at problems, which is what happens.*"(Flyvbjerg, Stewart & Budzier, 2016)

The problem is wasted time due to faulty planning and scheduling, in addition to a lack of proper control over project progress. The Mitigation Planner as discussed in Chapter 4 "*Scheduling with allowance of mitigations on-the-run*" of the book "*Stakeholder-Oriented Management, Tools and Concepts*", IOS Press, 2011, written by Lex A. van Gunsteren, will be discussed later in this research to show how it could be an effective tool to prevent such serious time squeeze from happening, which ultimately leads to the large spike in cost at the later stages of the project.

Furthermore, as presented in the following chapter about the Rio 2016 Olympics, there were several problems faced during construction of several of the venues. Below is a list of the general problems that were faced, which will be further elaborated on in chapter 2:

- Logistic problems
- Bankruptcy
- Corruption scandal
- Safety and security problems
- Untimely payments
- Late contract awarding
- Workers striking

With proper planning and scheduling, along with the suitable mitigations these problems could have been dealt with in a better manner.

1.3 Objective

The objective of this research is to show how the Mitigation Planner can help provide better planning and control over project activities to avoid the time squeeze faced in organizing the Olympics, which will in turn help spread the cost over the entirety of the project rather than have a hefty spike in spending at the end to make up for lost time at the beginning.

The Mitigation Planner is based on a PDM software that performs probabilistic network analysis to determine the probability of timely project completion. The software calculates skewed probability distributions for each activity's duration. This is done through the input of three values by the user, for each activity: Optimistic (10% probability that reality will be better), Pessimistic (10% probability that reality will be worse), and Most Likely. Following the input of these values, each activity is given a random value and run through a Monte Carlo simulation. Rather than having one critical path, like in conventional planning methods, this provides us with the different possible critical paths, which are even ranked according to risk. A repetition of the Monte Carlo simulations is done for each activity, ultimately providing us with the probability distribution for the total project duration. Using this, the probability of project completion can be determined. The Mitigation Planner helps determine the probability of timely completion at any point in time. If the probability of completion is kept above 50%

at all times by means of mitigations – i.e. corrective measures taken during execution, timely completion is ensured. This is called the 50% threshold. If the probability of completion of a certain task decreases below acceptable levels, a corrective measure, such as changing contractors or adding more workforces can be implied in order to finish the task on time (Van Gunsteren, 2011).

Additionally, during execution and as the project progresses some activities would have been finished while other are yet to be started, hence activities can be divided into three groups: Past, Ongoing and Future activities. In the Mitigation Planner there exists an option in which past activities can be set to their historical values, since they are already known, rather than inputting the three estimate values stated earlier. This decreases uncertainty and provides us with a more accurate project completion time, as some values would already be set in stone. This means the more activities are done, the more accurate our results will be, so repeating the process throughout project execution could be a helpful control tool, to make sure the project is on time. More on the Mitigation Planner in chapter 4 of this research.

The 2016 Rio Olympics will be analyzed as a test case to establish if proper application of the Mitigation Planner, and in particular maintaining the 50% threshold, could have prevented the unbalanced spending over the available seven years.

To answer this question the following information is relevant:

1. Spending as a function of time as has taken place in reality
2. Spending as a function of time while maintaining the 50% threshold

The analysis will be made for a single case, namely the Rio Olympic Village. If successful, the Mitigation Planner could then be used for monitoring the progress of all major construction projects of the Olympics. Ultimately, the aim of this research is to show that the International Olympic Committee can use the Mitigation Planner as a tool; a tool that, if enforced by the IOC on the host countries, can make sure that the host country does not face time problems in construction due to insufficient or inefficient planning and scheduling. This would allow entrusting the Olympic games to less developed countries, with less skilled individuals such as Brazil.

1.4 Research Question

The research question of this thesis can be formulated as follows:

"Can the Mitigation Planner prevent the unbalanced spending in organizing the 2016 Rio Olympic games?"

Sub-questions:

1. What is the actual situation of spending as a function of time?
2. What lead to the delays, hence the time-squeeze, in construction?
3. How could these delays been avoided?
    a. What kinds of mitigations are available?
    b. Are the mitigations feasible (available resources, and identified early enough)?
4. What is the spending as a function of time while maintaining the 50% threshold with the available and feasible mitigations?

1.5 Research Methodology

This section will describe the research methodology and it consists of mainly three parts; Literature review and data collection, the application of the mitigation planner, and finally the presentation and analysis of results.

1.5.1 Literature Review and Data Collection

The first step in this research is a thorough literature review to gather all the necessary information regarding all venues (costs/schedule overruns). General information about organizing the entire Rio Olympics with all its venues is collected to pursue an overall picture of what went wrong, and what kinds of delays and cost overruns the organizers dealt with. This information was gathered just to make an overall picture of how badly organization was in fact in the Rio Olympics, and how, theoretically, the mitigation planner could have helped alleviate this burden and make planning easier and more accurate.

First step was to gather information on all the venues and infrastructure, at the Rio Olympics:

1. Planned vs. Actual Cost (cost overruns)
2. Planned vs. Actual Construction Schedule (time delays)
3. Causes of problems and delays
4. Possible mitigations

Second, more detailed information was gathered about the Olympic Village, as it is the main case in this study, to determine, if successful, how the improvement the mitigation planner provided to constructing the Olympic Village, can ultimately be transferred to the bigger picture and to all the projects in organizing the Olympics. Information needed for this will be:

1. Detailed construction schedule of the Rio Olympic Village (Gantt charts, network diagrams, etc.)
2. Detailed construction costs (as a function of time) of the Rio Olympic Village
3. Causes of problems and delays
4. Possible mitigations

1.5.2 Mitigation Planner

The next step after gathering all the required information was to input it into the software and analyze the effect the Mitigation Planner can have on the construction of the Olympic Village. As stated earlier, the mitigations have to be feasible; two conditions have to be fulfilled for successful implementation of these mitigations (Van Gunsteren, 2011):

1. A redundancy of capable people and financial resources has to be available to be assigned to the mitigations.
2. Forthcoming disasters have to be spotted at such an early stage that sufficient time is available for implementation.

When all the mitigations are checked, simulations are run using the PDM software for the construction of the Village with and without mitigations. This will allow us to compute the probability of timely completion for both cases. Moreover, 5 different simulations will be run at different stages of construction to show the effect of continuously following up with tasks statuses has on the results of project completion time from the PDM software.

1.5.3 Data Analysis

Finally, analyze and explain results. Present the results in the form of tables and graphs and illustrate what they represent. The cost vs. time graph for each of the aforementioned simulations will be presented and compared to show the difference in payment schemes and their effect on overall spending. Finally show how the use of the Mitigation Planner can help improve organization of the entire Olympics, with all the venues, based on the results of the PDM simulations and cost vs. time graphs of the Olympic Village.

1.6 Research Structure

Following this introductory chapter will be a chapter presenting the information gathered on the Rio Olympics 2016. It will entail a brief description of the event and the venues used, along with the information on the construction costs and schedule which will be used to identify the problems faced in order to come up with mitigations to deal with them. Also a brief description of the governance structure of hosting these games will be presented to identify who is responsible. Next, a chapter depicting the main case study of this research, namely a chapter about the Rio Olympic Village will be provided. In this chapter the more detailed construction costs and schedule of the village, with the 31 buildings in it, will be presented. Causes of problems and delays will also be identified in this chapter to look for possible mitigations, which will eventually be used, in the following chapter named Mitigation Planner. This chapter will start off with a brief description of what the mitigation planner is, its history and how it works. Next, the information gathered in the previous chapter about the construction cost and schedule of the Olympic village will be used along with the feasible mitigations classified in order to run simulations on the PDM software. The tests results will then be presented in the form of tables and figures and explained. Finally, the research concludes with a Conclusion and Recommendations chapter.

2. Rio Olympics 2016

On October the 2nd in 2009, at the 121st International Olympic Committee session in Copenhagen, Denmark, it was announced that the host city of the 2016 summer Olympics would be the city of Rio de Janeiro, Brazil. Six years and ten months later, the 2016 Olympic games were held in Rio from August the 5th till august the 21st. During this period, the city was host to more than 11,000 athletes from 86 different nations, competing in 306 events in 28 different sports. This multi-sports event was the first time the Olympic games were held in the South American continent. Reasons given as to why this is only the first time the Olympics are held in a South American country is the political instability, lack of money and/or infrastructure, but as the IOC usually tries to effect change in the countries chosen to host the games, as the games were awarded to Beijing in 2008 in an attempt to help introduce China to the world, or as it was in Seoul 1988, where the Olympics was a contributing factor to the formation of a civilian government. So is the case for Rio, trying to speed up the countries development through the hosting of the 2016 Olympics (Bradshaw, 2016).

Rio was one of the shortlisted cities to host this event, among the other three cities Chicago, Madrid and Tokyo. Rio scored a weighted average score of 6.4 compared to the 7.0 for Chicago, 8.1 for Madrid and 8.3 for Tokyo but still managed to win the bid. The fact that Rio got shortlisted over Doha who had a higher weighted average score (6.9) than Rio already caused some uproar, not to mention the controversies Rio caused when the city actually won over the higher scoring cities. Nevertheless, Rio scored highest in Government support, legal issues and public opinion, but lowest in safety and security.

As it is well known, things did not go smoothly in the seven years leading up to the opening ceremony, in fact, with 500 days to go only 10% of the building work in Brazil was completed, with some projects yet to have a fixed time-frame (Conroy, 2015). Construction of several venues had not even started with less than two years till opening day, and some contracts had yet to be tendered, "*setting the stage for a last-minute rush that will likely drive up costs*" (Eisenhammer, 2015). When compared to the London Olympics of 2012 at this stage, almost 80% of construction was already completed in comparison to the 10% in Rio. A corruption scandal at state-run oil company Petrobras, that worked with several companies delivering the Olympic projects which lead the smaller engineering companies into bankruptcy, not to mention the power contracts that had yet to be tendered out, which meant that Olympic venues that needed to be built in conjunction with the power supply also had to get delayed (Eisenhammer, 2015). This might be connected to the fact that Brazil had been suffering from a drought, and these water problems might have had an effect on the energy production as Brazil gets 70% of its energy from hydropower (Kaiser, 2015). Other prominent problems faced by Brazil in the run up to the games is the pollution of Rio's Guanabara Bay, which was host site for the Olympics' sailing and windsurfing events (Kaiser, 2015), was filled with raw sewage flowing from the suburb Sao Goncalo into the Bay. Even bigger garbage such as furniture or even human severed limbs were found stranded on the sands of the bay (Carney & Phelps, 2016).

These are just some of the generally known problems Rio had to face among other such as the threat of the ZIKA virus and several worker strikes. More detailed analysis on the competition venues will be given later in this chapter, depicting the different venues, their construction costs and construction schedule delays faced and possible mitigation that would have helped. Followed by that, in chapter 3, the case study of this research, Rio's Olympic village, will be defined with more depth illustrating the different construction phases and activities, along with their problems and possible mitigations.

2.1 Costs and Financing

This chapter will give a brief overlook over the cost of the Rio Olympics and how it was funded. Financial resources for the Olympics as stated in the Pre-Games Integrated Report from 2016 are obtained from private sources, such as sponsorships, ticket and merchandise sales, broadcasting revenue and contribution from the IOC (RIO 2016, 2016). An overview of the information gathered from that report is presented below.

The Rio Olympics cost a total of **$11.6 billion**:

- **Sports-related (Direct Capital Costs) = $2 billion**
  - These are the costs related to venue construction and are funded through 63% private funding through the PPP's formed with the governments for the construction and operation of these venues.
- **Operational Costs = $2.22 billion**
  - These costs as discussed earlier in the research include costs of operating the games such as athlete meals, uniforms and sports materials. These costs are 100% privately funded through sponsorships.
- **Indirect Capital Costs = $7.38 billion**
  - These costs are the Legacy costs, which have no direct effect on the Olympic sports venues. These costs include costs such as the infrastructure and the doping laboratories. These costs were 43% privately funded.

Overall Funding:

- 43% of the total budget ($4.932 billion) was through public governmental funding
- 57% of the total budget ($6.668 million) was privately funding

2.2 Governance Structure

This section will illustrate the governance structure taken place in order to provide a better understanding of responsibilities and authorities in hosting an event such as the Olympics. The next image represents this governance structure.

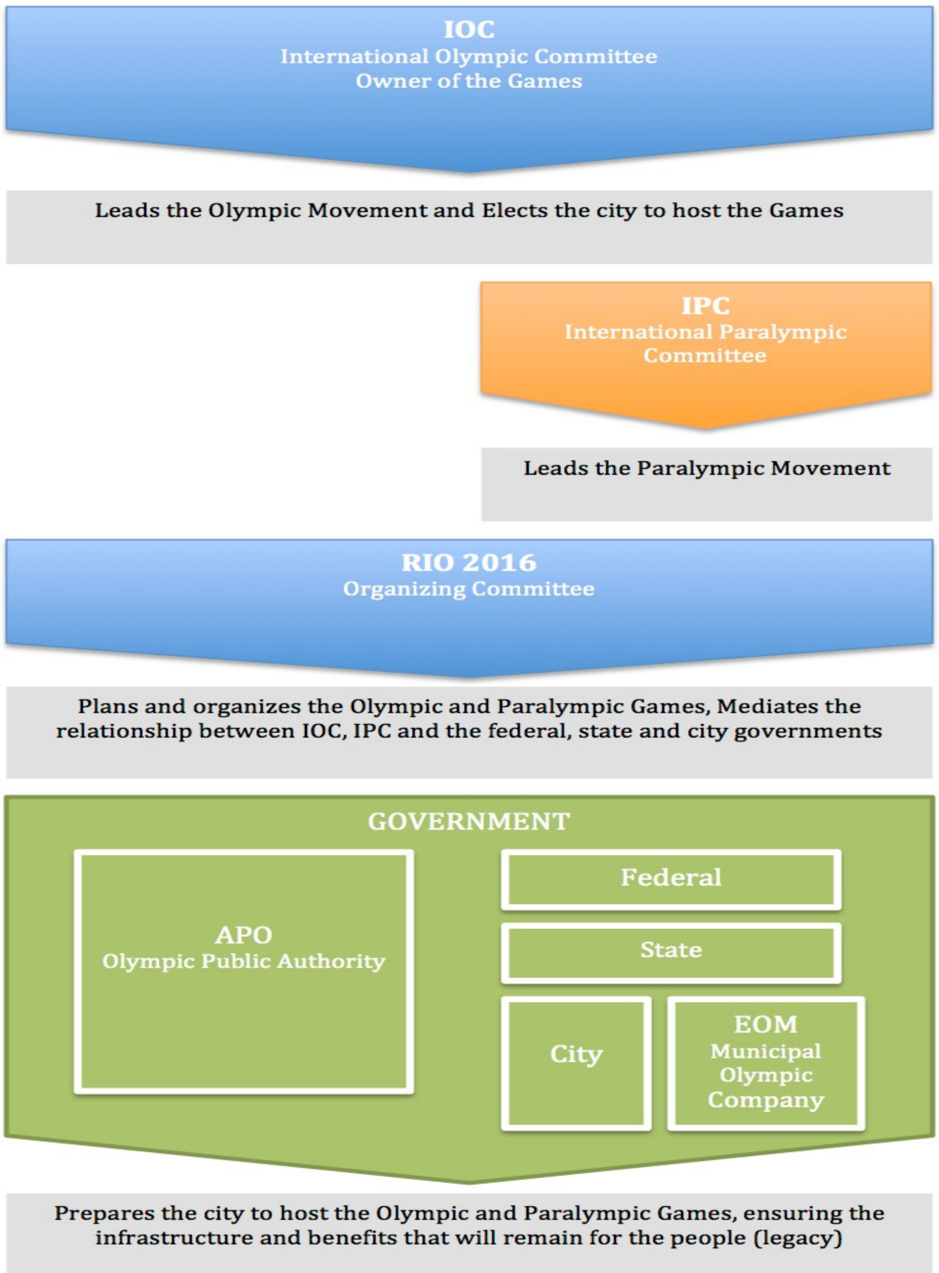


Figure 1 - Governance Structure (Figure Replicated from RIO 2016, Pre-games integrated report Rio 2016)

As can be seen in the figure above the IOC/IPC lead their respective movements as they work together with the organizing committee of the host city, RIO 2016 in this case, which in turn does all the planning and organization under the supervision of the IOC. The lowest level in this structure is the government who prepares the city to host the games, hence the government is responsible for ensuring all the venues and infrastructure is up to standard and ready to go by the time the Olympics start, which also includes the tendering of contracts.

A Public-Private Partnership (PPP) between the Municipal Olympic Company EOM and Rio Mais Consortium was made, which put Rio Mais (translated means "More Rio") Consortium in charge of the construction at the Olympics. Lead contractor of this consortium was Odebrecht Infrastructure, while other member firms included construction company Andrade Gutierrez and developer Carvalho Hosken. Rio Mais had to work with several other companies together at several sites. One of those sites is the construction of the Olympic Park, which was designed by AECOM when they were the winner of the General Urban Plan for the Olympic Park in 2011 (Winton, 2013), furthermore and more importantly for this research the consortium was also responsible for the construction of the Olympic village, more on which will be discussed in chapter 3.

2.3 Olympic Venues

The competitions were played in 32 venues distributed over four regions; Barra, Deodoro, Maracana and Copacabana as can be seen in the figure below.

Figure 2 - 32 Olympic Venues (Murai, G. (2016). Retrieved from: https://calconstructionlawblog.com/2016/07/25/the-road-to-rio-2016/)

These venues were either built from scratch such as the Rio Olympic Velodrome and the Olympic Aquatic Stadium, while others were only remodeled such as the Maracana Stadium and many of the football stadiums. Most of the venues are permanent and will stay after the Olympics, but some were only temporary and had plans to be transformed into something else such as the Carioca Arenas that hosted several sporting competitions throughout the games but had plans be turned into a training facility post games (RIO 2016, 2008). In the following two sections an overview of the venues with examples of some of the highest cost overruns will be given, followed by the identification of the problems that might have caused construction delays, and hence these construction cost overruns.

2.3.1 Constructions Costs and Cost Overruns

All in all Rio's cost overrun of sports-related projects added up to a cumulative of $1.6 billion, which amounts to a 51% cost overrun (Flyvbjerg, Stewar & Budzier, 2016). In this section we take a look at the differences in the costs planned vs. the actually cost of construction of some of the venues at the Rio Olympics. The values for the planned costs have been derived from the Olympic bid submitted by the Rio 2016 Olympic committee in 2008, while the values of the actual cost have been gathered from updated costs released by the APO (Autoridade Publica Olimpica), known in English as the Olympic Public Authority, after the completion of the games.

Each of the 4 regions has several venues, with the Barra region having the most with 15; here is a list of some of the venues with the highest cost overruns:

Venue	Planned Cost 2008 ($M)	Actual Cost ($M)	Cost Overrun ($M) (%overrun)
Rio Olympic Velodrome	39.707	44.82	5.113 (12.88%)
Olympic Aquatic Stadium	54.564	65.13	10.566 (19.36%)
Carioca Arenas 1,2,3 (Includes MPC & IBC)	409.207	505.5	96.293 (23.35%)
Olympic Village	566.76	894	327.24 (57.74%)

Table 1 - Cost Overruns: Planned vs. Actual

As can be seen from the table, these are just a sample of the amount of cost overruns faced by the organizers of Rio 2016. The Rio Olympic Velodrome was one of the most complicated projects of the Olympics with a large number of delays and construction problems that will be discussed in the next section. Furthermore the Olympic Aquatic stadium which was meant to be a temporary facility to be later dismantled and tuned into a community-swimming center had a cost overrun of $10.566 million. Not only did it have a cost overrun of 19.3% but also the plans to turn it into a community-swimming center were abandoned and the stadium was left to rot as can be seen in the next image (Otto, 2017).

Figure 3 - Abandoned Aquatic Stadium.

(Image retrieved from http://www.news.com.au/sport/sports-life/rios-olympic-aquatic-centre-left-in-ruins-after-grand-promises/news-story/f0d7a5aedfd314c41ae42f66b98d5ca3)

The cost overrun for the Carioca Arenas, which also includes the Main Press Center (MPC) and the International Broadcasting Center (IBC) was a huge $96.3 million, which is a 23.35% cost overrun. Finally the last example given in this table is the Olympic village. The Olympic village has a cost overrun of 57.74%, but more on this will be discussed in chapter 3, as it will be the main case study of this research.

2.3.2 Construction Schedule Delays

In this section we look at how the construction schedule of the venues was delayed, presenting some of the problems that halted the construction of the Olympic venues. One of the most troublesome venues with the most constructions delays was the Olympics Velodrome. The velodrome's delays were so bad that the two day test event that was initially planned for mid-March 2016, but then moved to April 30, due to delays in the installation of the wooden track due to subpar conditions among other difficulties faced, was completely canceled, leaving the track untested (The Associated Press, 2016). The subpar conditions relate to the fact that the timber being delivered from Siberia for the cycling track, arrived late into Rio's summer which meant it was too humid for the installation to go as fast as planned, which made this a ***logistics problem***. Furthermore, in May 2016, construction and operation contractor of the Olympic Velodrome, Tecnosolo, filed for ***bankruptcy*** hence leading to the cancelation of the contract by the Rio de Janeiro city government (Cutler, 2016). The contract was then handed over to another Brazilian company called Engetecnica, who had already worked on the project since February of that year (Reuters, 2016).

As stated earlier in this chapter, state-run oil company Petrobras was involved in a ***corruption scandal***. The scandal involved price-fixing, bribery and political kickback scheme, which ultimately led to several arrests. As this might not look like it would affect the organization of the Rio games directly, it does affect the five companies that were working on projects in the Olympics while working with Petrobras. The five companies involved were Odebrecht, who are involved in more than half the projects at the Olympics, one of which is the Olympic village; the other four companies are OAS SA, Andrade Gutierrez SA, Queiroz Galvao and Carioca Christiani Nielsen Engenharia SA. OAS, one of the biggest construction firms in Brazil, was responsible for constructing several Olympics venues at the Deodora region, filed for bankruptcy in March 2015 (Eisenhammer, 2015). The aforementioned arrests included the arrest of former Chief Executive Officers (CEO) of Odebrecht S.A and Andrade Gutierrez in June of 2015 (Fonseca, 2016)(Connors, Jelymayer & Kiernen, 2015). Ultimately the result of this scandal was the suspension of all payments from Petrobras to the companies, hence leaving the companies working on the Rio Olympics with a serious cash squeeze. With no money to spend, construction got delayed.

Furthermore accumulation of hazardous material in addition to excavation and underpinning problems lead to ***safety and security problems,*** not to mention ramps being too steep for workers to work on in the Olympic Velodrome, while at the Olympic Tennis Center workers were halted from working due to missing safety rails.

Slow, untimely, payments are a regular problem for the construction industry in Brazil, especially with government contract, which make up the majority of contracts in the Rio Olympics. As a result project activity comes to a stop when cash flow is not on time as was experienced at the Ipanema beach which needed repair works but did not get the money to do so (Eisenhammer, 2015).

Another problem faced was energy. During the bidding process for the energy contract, which was awarded only eight months prior to the games, in comparison to London 2012 where the contract was awarded 20 months in advance (Eisenhammer, 2015). This caused a problem for the projects being built in conjunction with the power grid as thousands of kilometers of wiring and panels had to be laid (Eisenhammer, 2015). This problem is a problem of ***late contract awarding***.

The ***workers striking*** caused another delay, as they were asking for an 8.5% pay rise because they said they were being pressured by the economic downturn of the aforementioned scandal with Petrobras, while the employers were only offering 7.3% (Gaier, 2015).

2.4 Possible Mitigations

The mitigations in this section are only something to think of while looking at the big picture of the Rio Olympics. As can be seen in the former section some of the problems causing construction delay are the following:

- Logistic problems
- Bankruptcy
- Corruption scandal
- Safety and security problems
- Untimely payments
- Late contract awarding
- Workers striking

The untimely payments and bankruptcy problems can both be attributed to the corruption scandal, which involved several companies working on the Olympic projects. This can be avoided through better knowing the companies involved and through more transparency between the actors involved. Another mitigation is to have other contractors ready to step in when one fails to perform or goes bankrupt.

The logistics and safety and security problems are a responsibility of the contracting companies working on the respective projects. The problem with the logistics could be mitigated through better planning and understanding the materials that are being used and how they are affected by conditions to avoid the mishap with the timber that arrived late from Siberia and delayed construction of the cycling track. Safety and security problems could have been avoided with a better more skilled safety and security team, or at least training the teams available to take the measures required to go forth with a safe and secure construction process. Investing more in having skilled teams that are up to the task might come more expensive at the beginning but it will pay out at the end as the delays will be less and extra payments will be avoided to make up for lost time.

For the late contract awarding, as the case for the energy, could be caused by the effect of having the feeling of having enough time and postponing, causing a time squeeze which will increase the cost. The only thing to do here is to start earlier with the bidding process, so incase major bidders such as Glasgow-based Aggreko, who has been providing energy for the past 9 Olympic games (Eisenhammer, 2015), pulls out, there is enough time to find a proper substitute.

Finally the problem with having workers strike can be attributed to a bad connection between the laborers and the management. This can be avoided through several ways, two of which are implementing a labor-management relations program and removing communications barriers (Lohrey, 2017), making them feel involved rather than being “used”.

This chapter gave a brief overlook of the Rio Olympics governance structure; followed by the presentation of the construction cost overruns of some of the Olympic venues, along with a description of several reasons that caused construction delays, which ultimately lead to the unbalanced spending. The purpose of this study is to look deeper into the construction, with the different phases and activities, in order to study how the mitigation planner with the mitigations on the run could improve project performance in the means of balancing out the spending over the overall lifetime of construction, rather than having a large cost upsurge at the end. This will be done in the next chapter where the construction of the Olympic village will be taken under the loop. The construction schedule will be studied to understand what happened in the construction process, what was the cost as a measure of time, and what were the causes of the delays.

3. Rio Olympic Village

The Rio Olympic Village is located in west part of Rio de Janeiro called Barra da Tijuca, and is the largest Olympic village to date. It is part of the real estate development Ilha Pura, which stands for Pure Island which covers a total area of approximately 820,000 $m^{!}$, with a total built up area of 1,700,000 $m^{!}$ including the Olympic village (Senra et al., 2016). The Olympic village takes up almost a quarter (200,000 $m^{!}$) of that area as can be seen in the figure below.

Figure 4 - Ilha Pura Olympic Village (Ilha Pura, 2014. Retrieved from: https://www.slideshare.net/felizimovel/ilha-pura-vila-olimpica)

The village comprises of 31 buildings divided over 7 condominiums, up to 17 floors each, resulting in a total of 3,604 apartments, which can hold up to 17,950 people (RIO 2016, 2016). The total built up area of these 31 buildings totals to approximately 420,000 $m^{!}$. In addition to the 31 buildings, the village also encompasses a park of the size of 65,000 $m^{!}$, and other shopping and wellness facilities. The 3,604 apartments in the 31 buildings are made up of 11 different typologies. These typologies differ in number of bedrooms; 2, 3 or 4; and also in surface area: 77-160 $m^{!}$. Four of these typologies were found in literature review and through the Ilha Pura homepage (www.ilhapura.net), and hence are 100% accurate, while the remaining three had to be deduced from the values already known and the images that were found of the master plan, resulting in the following 7 typologies (Earlier it is stated that they are 11 typologies but that is because some have the same configuration with slightly different measurements):

- Given Values
  - 2 bedrooms: 77-82 $m^{!}$ (DOUBLE SUITES/PURPLE)
  - 3 bedrooms: 131 $m^{!}$ (3Q+DEP. FLEX/RED)
  - 2-3 bedrooms: 85-115 $m^{!}$ (2Q+3Q FLEX/DULL YELLOW)
  - 4 bedrooms: 160 $m^{!}$ (4Q FULL/LIGHT PINK)
- Deducted Values
  - 3 bedrooms: ~100 $m^{!}$ (3Q PRIME/ BRIGHT YELLOW)
  - 3 bedrooms: ~123 $m^{!}$ (3Q+ REV E 3Q/ORANGE)
  - 4 bedrooms: ~115 $m^{!}$ (4Q PRIME/DARK PINK)

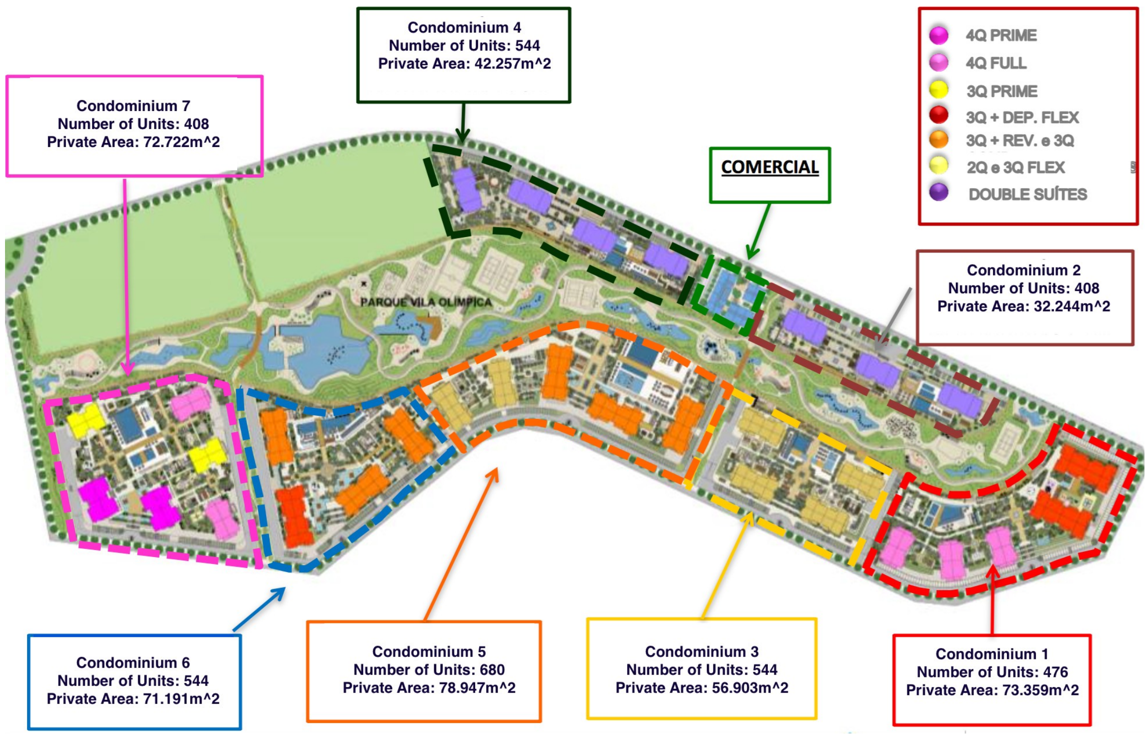


Figure 5 – Olympic Village Masterplan (Ilha Pura, 2014. Retrieved from: https://www.slideshare.net/felizimovel/ilha-pura-vila-olimpica)

The writing inside the brackets is an indicator for each of the different apartment types shown in the legend of the figure above which presents the master plan of the Olympic village with the 31 buildings and their corresponding apartment typology. In the very start the original plan had 9 condominiums but were then reduced to 7, while the numbering on the figure shows condominiums 1 through 7, in the original documents found condominiums 6 and 7 are originally labeled as 7 and 9 respectively. As this does not affect the course of this case study, the numbers were changed so that they are chronologically right for the sake of avoiding misunderstanding.

3.1 Project Structure

The organization of Rio 2016 used Public-Private Partnerships (PPP), getting local firms to cover the cost in return for permission to build real estate, as was the case for the Olympic village. As stated in chapter 2.2, a PPP between Rio de Janeiro Municipality, and the Rio Mais consortium was made. Within this consortium a joint venture of Norberto Odebrecht, the lead contractor, and Carvalho Hosken was formed and called the Ilha Pura Empreendimentos Imobiliarios, with plans to construct the village for the Olympic games and selling the apartments after. Caixa Economica Federal (CEF), a government-owned financial institution, funded the Olympic Village project with a loan of R$2.4 billion, which is equal to around $720 million (Belen, 2017). This was the cost of construction of the Olympic village; while the land cost was R$579 million, which is equal to and estimate of $174 million (Brasil Governo Federal, 2016).

The Ilha Pura Empreendimentos Imobiliarios is a real estate development joint venture founded in 2011 and created for the purpose of developing the new neighborhood in Barra da Tijuca. As stated earlier the joint venture was made up of two of the most prominent construction companies in the industry in Brazil; Carvalho Hosken, who was the developer and also the landowner on which the village was built, and Odebrecht Realizations Real Estate who were the constructors of the project and the lead contractor (Ilha Pura, 2014).

3.2 Construction Schedule and Delays

Opposed to the previous chapter, in this chapter the construction schedule and delays section is presented before the construction cost and cost overrun as the research aims to show how the improper planning and the delays lead to the cost overruns and more specifically the unbalanced spending. A preliminary Gantt chart, depicting the construction timeline of the Olympic village found in the candidature file for Rio de Janeiro to host the 2016 Olympic and Paralympic games can be seen below.

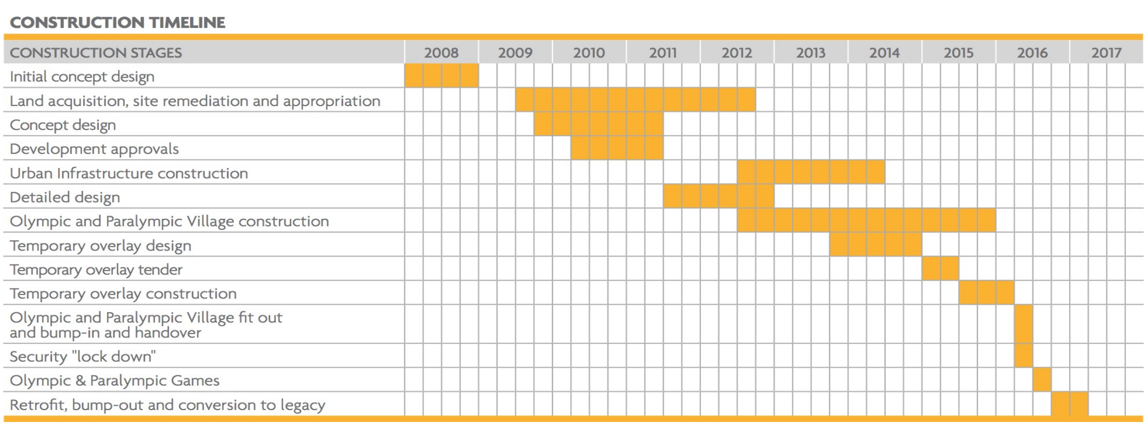


Figure 6 - Preliminary Olympic Village Gantt Chart from 2008 (Figure Retrieved from *Candidate File for Rio de Janeiro to host the 2016 Olympic and Paralympic Games*, 2008. Retrieved from: https://www.opusflow.nl/OpusFlowCRM/volume_2_eng_0_pdf.pdf)

According to the figure displayed above, the initial plan given as part of the bid, was that construction would start in the third quarter of 2012, which means earliest in July and latest by September 2012, but through a conversation conducted with Mr. Allan Mentzingen De Oliveira, a member of the real estate team responsible for the construction of the Olympic village, it was deduced that the actual construction and hence the foundation phase did not start till February and some even till March of 2013, resulting in an approximate six month delay from the preliminary timeline. Furthermore Mr. Oliveira also concluded that the final phases of facades, coating and internal finishes was completed by May-June of 2016, which is about six months late when taking the preliminary timeline into consideration which has the construction of the village done by the end of 2015. This delay leads to the time squeeze and hence the unbalanced spending since construction is delayed and needs to be sped up to be able to have the buildings ready for the Olympics.

Construction of the seven condominiums entailing the 31 buildings overlapped. When taking a look at the master plan in figure 2, construction started with condominium 1 and moved to the right, constructing the condominiums in sequential order from 1 to 7, with construction of respective condominiums starting after an approximate lag of 8 weeks (till half of the construction of the foundation of the previous condominium is finished).

Macio Polidoro, former Director of Communcation of Latin America and Caribbean Division of Odebrecht and current Director of the Communications Department of Odebrecht, provided valuable information regarding the construction of the Olympic village. The Gantt chart for the last condominium (condominium 7) can be seen below.

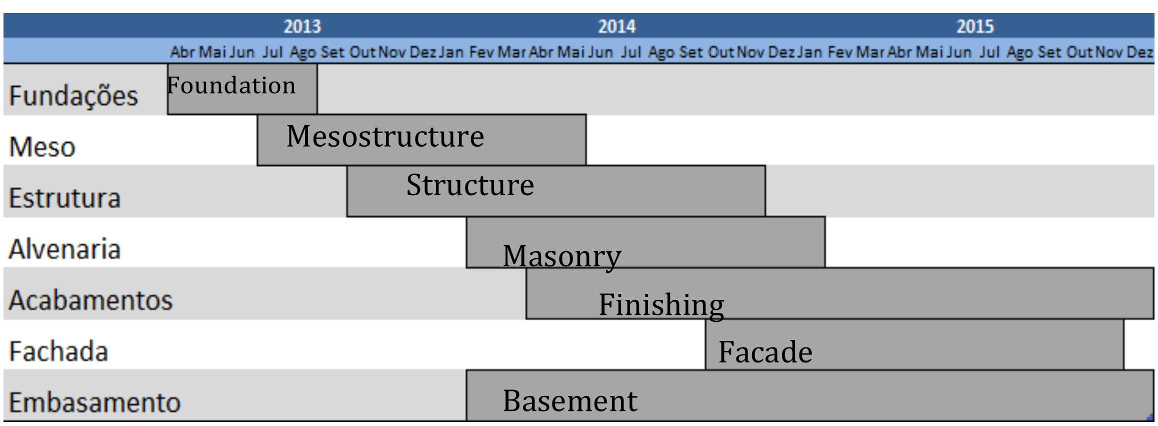


Figure 7 - Condominium 7 Gantt Chart (Ilha Pura. (2017). Da construcao ao legado)

The translation of each of the seven activities shown above is written within the bars. For the finishing, the expanded chart can be found next. The basement activity entails all the external features such as gardens and pools. Following the given Gantt chart for the last of the seven condominiums (condominium 7), construction should have ended December 2015, but that was not the case as Mr. De Oliveira explained that the final phases of façade, coating and final finishes did not finish till May-June

2016, mere months before the reception of the athletes and staff. As stated earlier the expanded "Acabamentos", finishing activities, can be seen below.

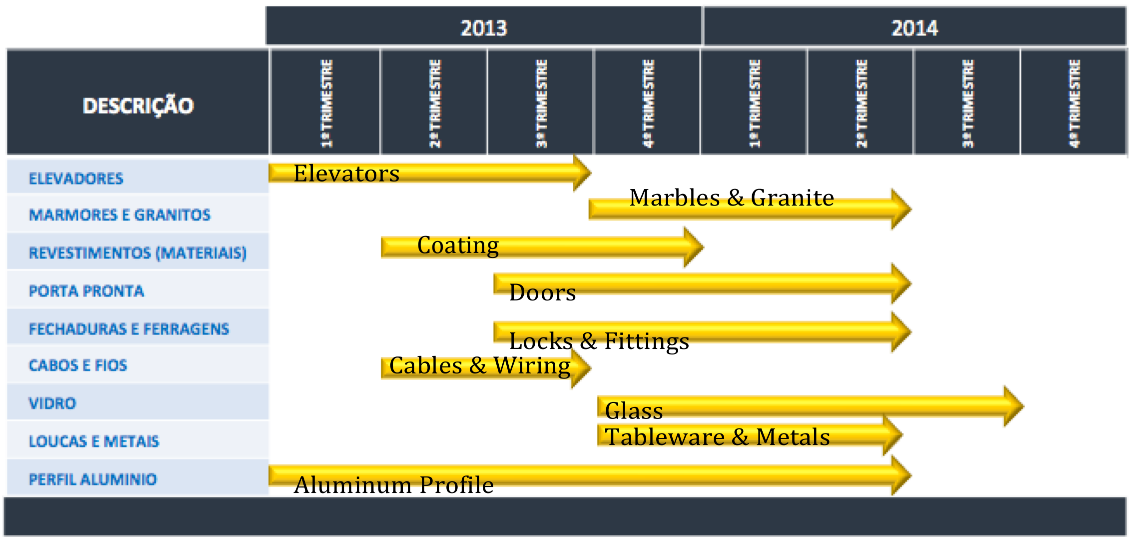
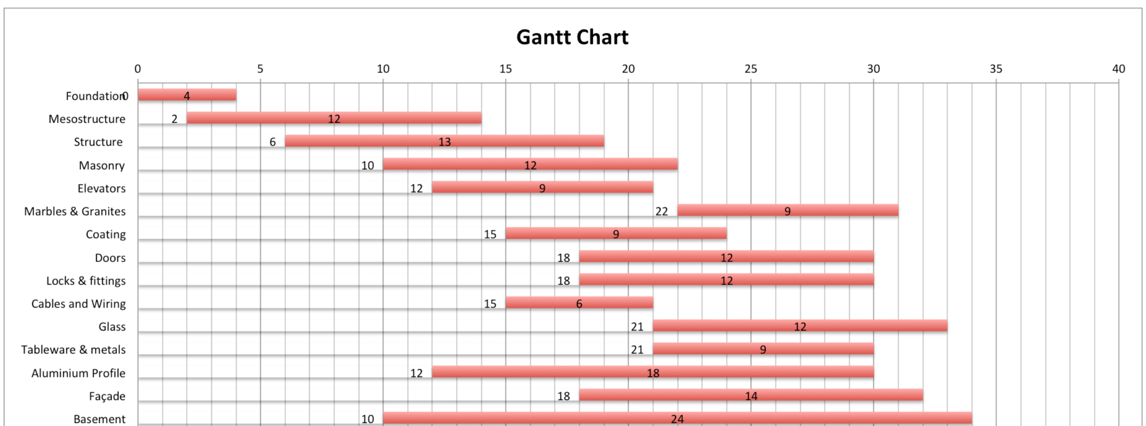


Figure 8 - Finishing Expanded (Acabamentos) (Ilha Pura, (2017). Da construcao ao legado)

Once again, the translation for each of the activities shown above it presented inside the bars. Given these two graphs do not align chronologically, the following adjusted Gantt chart was produced using input from both graphs:



	Basement	Façade	Aluminium Profile	Tableware & metals	Glass	Cables and Wiring	Locks & fittings	Doors	Coating	Marbles & Granites	Elevators	Masonry	Structure	Mesostructure	Foundation
Start Month	10	18	12	21	21	15	18	18	15	22	12	10	6	2	0
Duration (Months)	24	14	18	9	12	6	12	12	9	9	9	12	13	12	4

Figure 9 - Gantt chart for the construction of one condominium

For simplicity reasons instead of using the name of the month for Gantt chart, the months are labeled as numbers starting at 0. This will later make it easier to input the data and test it. The numbers before the red bars are the start month for the following activity, and the numbers inside the red bars are the duration of each activity. The Gantt chart above depicts the Gantt chart of one condominium. All 7 condominiums have very similar Gantt charts; therefore this one will be used to model them all.

In an interview with Mr. Joao Carlos Moog Rodrigues, Director at RASA engenharia & construcao, one of the contracted companies working on the village it was deduced that the main problems faced during the construction of the 7 condominiums was labor resource. Below is a table depicting the maximum number of workers on site for each of the 7 condominiums that happened in October 2014.

	ILHA PURA	Third Parties	TOTAL
Condomínio 1	196	925	1121
Condomínio 2	160	564	724
Condomínio 3	194	646	840
Condomínio 4	172	623	795
Condomínio 5	229	804	1033
Condomínio 6	180	756	936
Condomínio 7	185	730	915
Central /Concrete/Park	166	384	550
TOTAL October/14	**1484**	**5432**	**6914**

Table 2 - Maximum number of workers on site (Ilha Pura. (2017). Da construcao ao legado)

The “Ilha Pura” number depicts the number of laborers from the Ilha Pura joint venture, while the “Third Parties” are laborers contracted from other firms as Mr. Rodrigues made it clear that the lack of labor resources required them to contract other additional companies from Rio, Sao Paulo, Minas Gerais and Espirito Santo. The average numbers of laborers on site ranged between 5,500 and 6,000 laborers, and despite the added labor forces from the third parties, labor resources were still lacking. The lack of labor resources led to delays, an average of 3 months per condominium according to Mr. Rodrigues. This led to the addition of more labor resources, but the added labor forces were becoming less and less skilled, which is not optimal when a project is already lagging behind schedule, running over budget and has a fixed deadline.

3.3 Construction Costs and Cost Overruns

Not all 31 buildings cost the same to construct, as it was established in the conversation with Mr. De Oliveira, some condominiums were a lot more expensive than others, and that what depicted the differences in cost was the different typologies of the apartments, subsequently leading to the condominiums with 4 bedroom-units, as the ones in condominiums 1 and 7 (Dark Pink and Bright Pink), to be the most expensive ones. The table below shows the total cost of all the seven condominiums.

Condominium Number	Total Cost
Condominium 1	$ 91,310,147
Condominium 2	$ 43,486,343
Condominium 3	$ 74,135,912
Condominium 4	$ 62,549,722
Condominium 5	$ 101,811,170
Condominium 6	$ 88,058,143
Condominium 7	$ 96,917,072
Total:	$ 558,268,509

Table 3 - Cost per Condominium

This table shows what the respective condominiums actually cost. The cost of the 7 condominiums ($558 Million, average of $75.75 Million/Condo) by itself is almost equal to the estimated cost for the entire Village ($566 Million) from 2008 as stated in the previous chapter The remaining $336 Million to complete the $894 Million actual cost stated in table 1 in chapter 2 is the cost of the land property and infrastructure construction on which the Olympic village was built. And when taking into account the Gantt chart shown in figure 6, and the 8-week lag between start of construction of successive condominiums, the following graph showing the weekly cost for the all seven condominiums was manufactured.

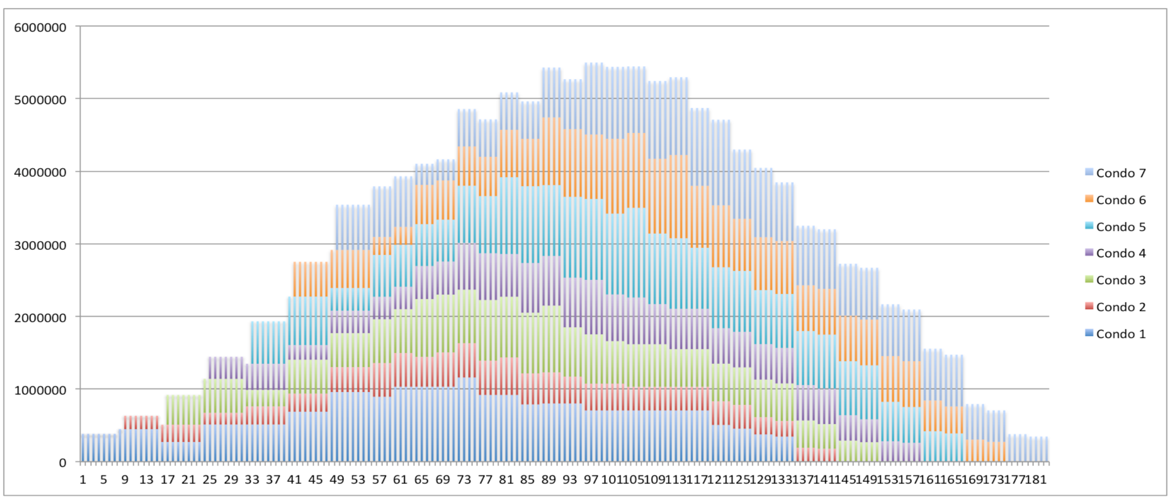


Figure 10 - Weekly Costs

On the y-axis it shows the amount in USD, while the number of week is represented on the x-axis. When comparing this graph to the one presented by the Ilha Pura in their presentation from 2017 some similarities can be drawn. This graph is shown next.

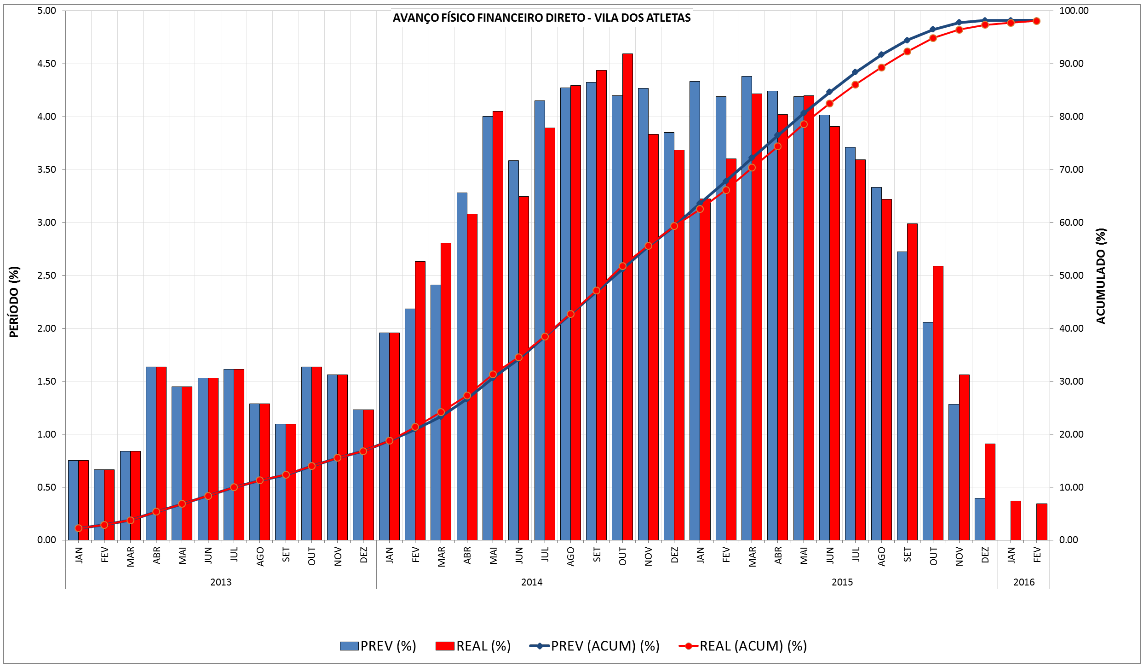


Figure 11 - Planned vs. Actual Costs (Ilha Pura, (2017). Da construcao ao legado)

Looking at the figure above, the blue bars labeled "PREV" represent the planned costs, while the red bars labeled "REAL" represent the actual costs, while the dotted lines for the respective colors show the accumulation, for the respective months shown on the x-axis. The y-axis on the left side shows the percentage completion, while the one on the right shows the accumulation that gets to 100% by February of 2016.

When looking at both graphs from figure 10 and 11, it is evident that there is a considerable rise in spending in the months form January 2014 till October 2015 on figure 11, corresponding to the rise in weekly cost between weeks 53 and 148 in figure 10. This can be attributed to two things. First is the fact that during this time, work is being done on all seven condominiums simultaneously, which automatically will lead to more spending. Secondly, given the fact the project did not start on time as earlier established, the time lost at the beginning in addition to the average 3-month delay caused by lack of labor resources and hiring lower skilled laborers would have caused the up rise in cost in order to catch up the delayed construction time.

In addition to the rise in cost over the aforementioned period of time, in figure 11 we can see the comparison between planned vs. actual costs. Here we can clearly see how in the early months of the projects all the way through the first year till January 2014, planned costs equaled actual costs. In 2014 we then have a series of months altering between higher and lower actual costs than the ones planned, but then if we look at the last six months of the project, September 2015 till February 2016, actual costs were higher than the planned costs. The last two months did not even have any costs planned, and while the figure indicates the project is complete at 100% on February 2016, it is not true; construction actually went deep into 2016 all the way up to June 2016. The values that are not stated in the figure are unplanned values to catch up for construction delay. This is caused by the time squeeze of starting late and having a lack of qualified labor resources.

3.4 Possible Mitigations

As it is clear by now the major problem causing the delays were the lack of labor resources and their respective lack of skill. When talking to Mr. Rodrigues about the problems faced and how they were dealt with, he mentioned that during the planning phase, specifically when calculating the budget, they calculated the budgets for individual condominiums and then added a 4% margin in order to guarantee the funds and incase problems occurred to not run over budget, but he also added that some of the buildings even had a 6% and 7% margin. This is not ideal as it gives the ones responsible an incentive to overestimate construction cost just so that they stay within budget, and this does not solve the problems that were actually faced with the lack of labor and skill. Knowing there is a fixed deadline, it is always better to start early and work on a constant rate, rather than start slow and then have the most work left in the finishing months. Spreading out the work would have made it easier to see that one is not on schedule, and also allow for easier and possible cheaper mitigations than being rushed finishing the project and all the delayed tasks at the end. Using the Mitigation Planner to schedule out weekly activity and set milestones could have had a positive effect, given the fact that it plans mitigations on the run rather than simply adding a 4% or 6% margin to the budget.

Here are some of the mitigations proposed and that will be tested in PDM software:

- Adding skilled workforce
- Changing contractor
- Adding concrete accelerating admixture

Before testing these mitigations it is important to make sure they are feasible, which means they have to be available and the problems have to be identified early enough in order to plan in the mitigations on the run. As stated earlier construction faced major problems with the labor resources and finding skilled workers, which makes the first mitigation “Adding skilled workforce” unfeasible at start, but if the problem of lack of skilled laborers was identified early enough, these “unskilled” laborers could be trained into becoming skilled laborers. Rather than dealing with the fact of having unskilled laborers the entire time and losing more time, and hence money, than necessary, training them at the beginning and spending more at the start can go a long way in the means of better construction quality from the laborers. It might even lead to needing fewer laborers, as they are more skilled. The second mitigation “Changing contractor” can only be implemented if there are suitable contractors able of doing the job the contractor that’s being substituted could not do, or did not do efficiently. Finally the last mitigation “Adding concrete accelerating admixture” can only be implemented in the starting phases construction for the condominiums such as the foundation and structure, but this acceleration in work early might come costly at first but might avoid you delays later, which would cost even more.

In the next chapter the Mitigation Planner will be discussed and the mitigations proposed in this chapter will be tested in the PDM program to try and show how using the Mitigation Planner can help avoid this unnecessary cost at the end to make up for the delays, hence balancing out cost over the entirety of the project.

4. Mitigation Planner

To start of this chapter, we take a look at the book titled "Stakeholder-Oriented Project Management: Tools and Concepts" written by Lex A. van Gunsteren (2011). This book describes several ways in which to manage projects, and one way of doing so is *Scheduling with allowance for mitigations-on-the-run*, which is the title of chapter 4 in the book which explains how the Mitigation Planner, specifically the software it uses which is called the PDM, short for *Precedence Diagram Method*, software came to existence and what it aimed to do and how. This chapter will give a brief explanation of that. Followed by the data analysis and explanation of results of the simulation runs concerning the Rio Olympic village.

4.1 History of the Mitigation Planner

As the author implies in the first few paragraphs of chapter 4 of the book, "*the fundamental error in all current planning models is the implicit assumption that execution will take place as indicated by the planning software" (Van Gunsteren, 2011)*. What is meant is that the thought that after the initial planning and scheduling of activities the project manager sits back and does nothing when things do not go as planned, while in reality the manager will take any action necessary in order to ensure project completion within the given time period. The manager will take several mitigations in order to amend the activities that did not go as planned, but these adjustments are rarely taken into account when the planning occurs. This is where the creation of the software using probabilistic network planning with mitigations-on-the-run comes in handy.

There are several management techniques that came before and are still being used now such as the *Work Break-down Structure* (WBS), which is the most basic of them divides the total work to be done into smaller manageable work units known as work packages or activities, such as in figure 12.

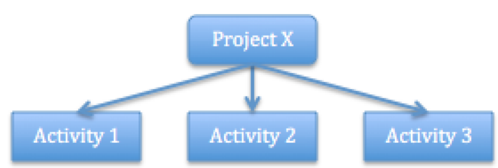


Figure 12 - Work Breakdown Structure

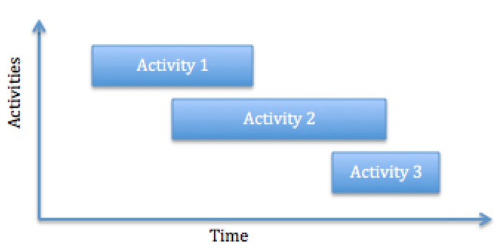


Figure 13 - Gant Chart

Furthermore, the *Gantt chart* takes these work units and puts them into a visual representation of the activities scheduled over time, as can be seen in figure 13. It shows the start and end time of each activity.

Moreover the *Critical Path Method* (CPM) is a project modeling technique that takes into account the interdependencies of the activities in the network planning and identifies the critical activities as shown in figure 14. The critical path is the sequence with the longest duration, making the activities on that path critical activities, meaning that delay in any of those activities will delay the entire project, so they are planned accordingly.

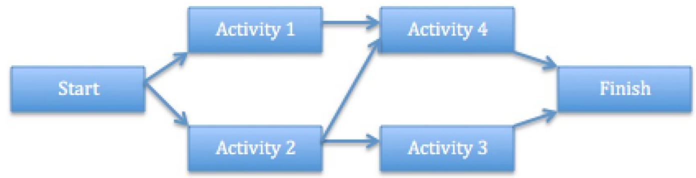


Figure 14 - Critical Path Method

The Gantt chart and the CPM both use single input values for the activities, which means there is theoretically no uncertainty and everything will go 100% as planned, which is not realistic, and will lead to delays when unforeseen mistakes happen. Finally the *Program Evaluation Review Technique* (PERT), which is the base of the Mitigation Planner, is a statistical management tool designed to analyze and represent all project activities based on time estimates. It uses time estimates such as optimistic (10% probability of being shorter)/most likely/pessimistic (10% probability of being longer) for single activities to come up with the probabilities of completing this single task in a given duration. The same is done in the Mitigation Planner. Using the three aforementioned estimates a skewed probability distribution, such as the beta distribution, is assumed for each activity. This is done with every single activity to ultimately identify the probability of completing the entire project in the minimum time needed, as can be seen below.

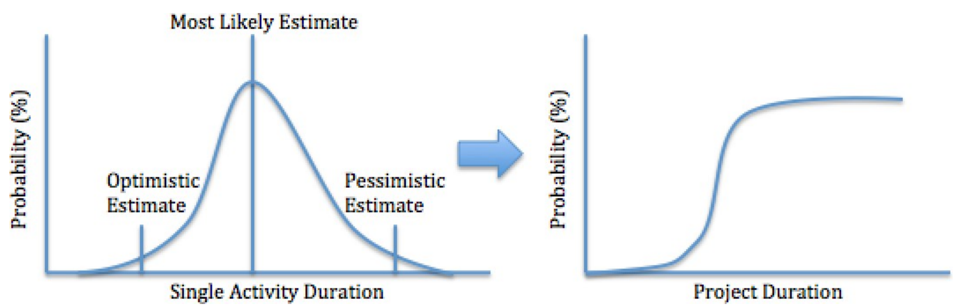


Figure 13 - Probability of completing single activities and total project duration as with PERT

As with PERT, the Mitigation Planner uses the statistical aspect with some slight yet significant adjustments. The difference and the element that makes the Mitigation Planner more realistic and precise in terms of planning is the fact that it enables the user to integrate mitigations into the planning process, which none of the aforementioned techniques do. A further improvement the Mitigation Planner has on the previously named management techniques, which compared to PERT which only provides information on one critical path, is the fact that the Mitigation Planner ranks risks using Monte Carlo simulations to provide the user with more than one critical path with its respective risk ranking (Van Gunsteren, 2011). What the Monte Carlo simulation does is carry out a critical path simulation, which uses the activities durations obtained from the probability distributions formed using the afore mentioned time estimates for every activity (optimistic/most likely/pessimistic). This is done several times, for example 2000, which then provides the probability distribution of the duration of the entire project. All this is done while a counter keeps track of the number of times each path was critical within those 2000 simulations; providing a ranking in critical paths according to risk, which is the probability of completion. This specifies the probability the path chosen will actually be the critical one in reality.

In addition to the mitigations-on-the-run and the ranking of critical paths, the Mitigation Planner also accounts for availability of qualified persons needed for the devised mitigations, to make sure the resources and people required for the mitigations are also available, and being used in the most efficient manner. This is possible through an option in the software that inputs the mitigations along with their set of "*Skills*" required. Using resources and personnel efficiently can keep the team small. Additionally it is worth mentioning that well rounded individuals who can do multiple tasks are preferred over specialists, as a smaller team of well rounded individuals is better than a team with a large number of specialists as each person brings with them a cost and an opportunity cost (Van Gunsteren, 2011).

The aim is to use the minimal amount of mitigations, while staying within the target completion time, in order to minimize costs. The Mitigation Planner, while it can be a benchmark to compare progress against the schedule, it is not meant to control progress but rather to schedule weekly activities for the project. This is because when used as a control tool, the user can always add a cushion to the time estimates to stay on the safe side, which is not optimal management of time and resources. When used as a scheduling tool, the Monte Carlo simulations provide information on which activities are the most frequent ones that needed mitigations, making it easy to pinpoint which activities will require added attention. As mentioned in the introduction chapter the aim is to have a probability of completion of 50% or higher, if the probability of completion is below 50% measures are taken in the form of mitigations to get the probability of completion of the specific activity to at least equal to 50%. When the probability is 50% or higher, timely completion is ensured; this is called the 50% threshold (Van Gunsteren, 2011). So to sum up with introduction on the Mitigation Planner, it uses the information provided in the form of activity durations estimates and activity costs, in addition to the cost and effect of mitigations and provides the probability of project completion over time. The aim of this research is not specifically to find the probability of completion but rather to show how using the Mitigation Planner to schedule and monitor progress of activities, can lead to a more evenly spread payment scheme compared to the traditional ones where costs tend to sky rocket at the end to overcome the lost time and construction delays, while maintaining a 50% probability of completion.

4.2 Data Analysis

From the information gathered, the following network diagram was formulated to better display the relations and interdependence between activities.

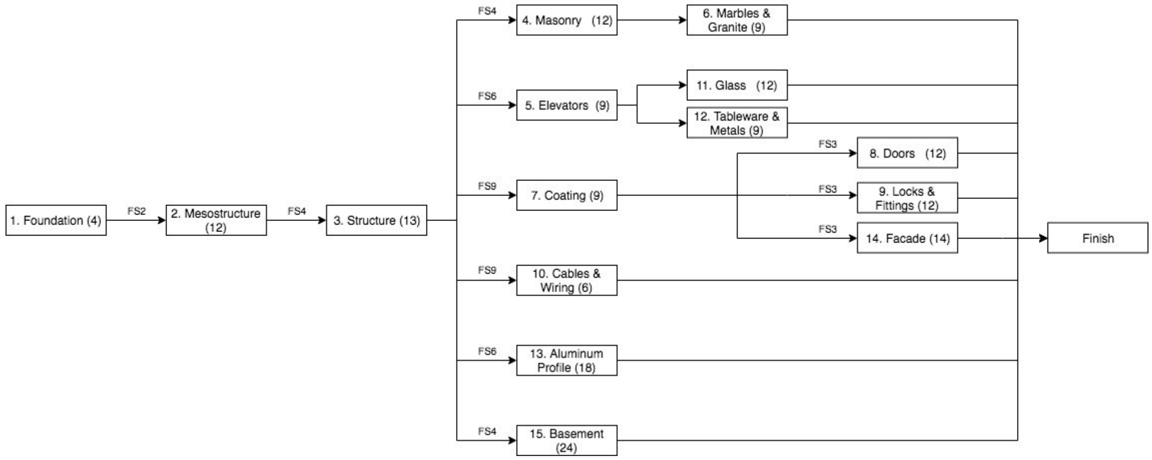


Figure 14 - Network Diagram for the construction of a single condominium

The network diagram above represents the activities written inside the boxes, with their duration in brackets. The arrows depict the relation between activities, where FS stands for Finish-to-Start, and the number following the "FS" is the lead-time. The arrows with no depiction represent direct FS relations. The relations between the activities can be found in the following table.

Number	Activity	Predecessor	Relation	Lead (months)
1	Foundation	-	-	-
2	Mesostructure	1.Foundation	FS	2
3	Structure	2.Mesostructure	FS	4
4	Masonry	3.Structure	FS	4
5	Elevators	3.Structure	FS	6
6	Marbles & Granites	4.Masonry	FS	-
7	Coating	3.Structure	FS	9
8	Doors	7.Coating	FS	3
9	Locks & fittings	7.Coating	FS	3
10	Cables and Wiring	3.Structure	FS	9
11	Glass	5.Elevators	FS	-
12	Tableware & metals	5.Elevators	FS	-
13	Aluminum Profile	3.Structure	FS	6
14	Façade	7.Coating	FS	3
15	Basement	3.Structure	FS	4

Table 4 - Relations between activities

In order to better analyze and test the construction schedule using the PDM software certain adjustments to the original Gantt chart had to be made. These Adjustments transform the entirety of relations between the activities into direct

Finish-to-Start relations, without any added lag or lead activities. The table presents the durations in the measure of months; this is for the sake of making the Gantt chart and network diagram easier to read, while the actual calculations and simulations done with the PDM software are done with a duration measure of "days" as it is more precise. The adjusted Gantt chart for the construction of a single condominium is as follows:

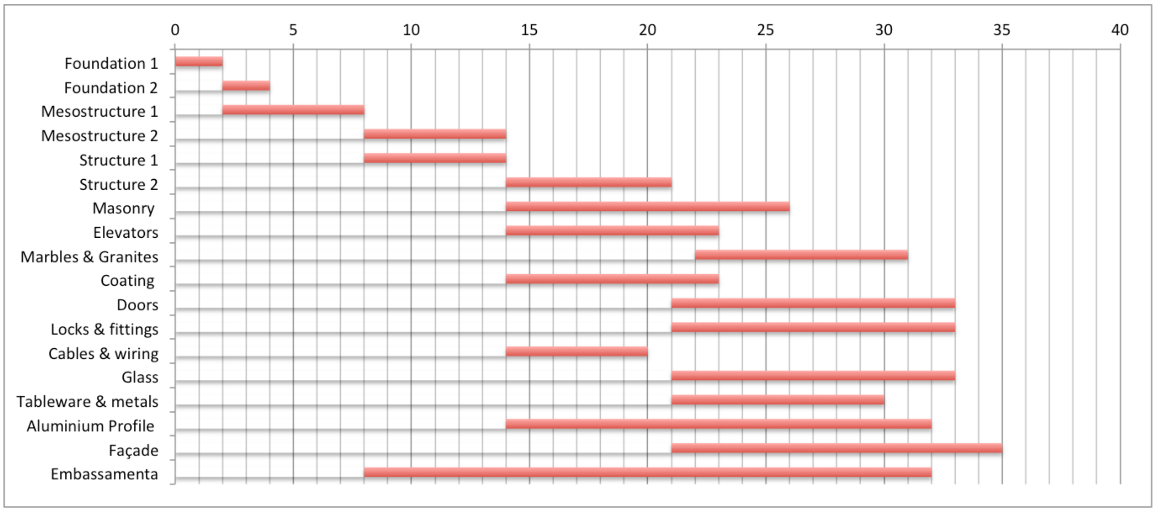


Figure 15 - Adjusted Gantt Chart

As is evident the Foundation, Mesostructure and Structure activities were all divided into two separate activities, this makes it possible to link them directly as Finish-to-Starts rather than adding a lag/lead. Dividing the activities into two is possible as the activities represent the construction of not only one Foundation/Mesostructure/Structure for one building, but rather each condominium has an average of 4-5 buildings this means for instance that dividing the Foundation into "Foundation 1" and "Foundation 2" represents the construction of the foundations of buildings 1 and 2 in "Foundation 1", followed by the construction of the remaining 2 or 3 foundations in "Foundation 2" for the remaining buildings in the condominium. Additionally some activities were slightly moved in order to be able to model them as direct FS relations, without affecting the overall outcome of the construction schedule. All in all, the entire schedule is very similar to the original with the slight adjustments stated above, resulting in a one month longer duration for the entire condominium. Otherwise all other activities and durations are identical to the original.

The table below sums up all activities and their relations of the adjusted Gantt chart that will be used for PDM testing.

Number	Activity	Predecessor	Relation
1	Foundation 1	-	-
2	Foundation 2	1.Foundation 1	FS
3	Mesostructure 1	2.Foundation 1	FS
4	Mesostructure 2	3.Mesostructure 1	FS
5	Structure 1	3.Mesostructure 1	FS
6	Structure 2	5.Structure 1	FS
7	Masonry	5.Structure 1	FS
8	Elevators	5.Structure 1	FS
9	Marbles & Granites	10. Coating	FS
10	Coating	5.Structure 1	FS
11	Doors	6.Structure 2	FS
12	Locks & fittings	6.Structure 2	FS
13	Cables and Wiring	5.Structure 1	FS
14	Glass	6.Structure 2	FS
15	Tableware & metals	6.Structure 2	FS
16	Aluminum Profile	5.Structure 1	FS
17	Façade	6.Structure 2	FS
18	Basement	7.Masonry	FS

Table 5 - Adjusted Relations

In order to test the probability of timely completion and run the Monte Carlo simulations first the three estimates for each activity have to be determined. The Most likely estimate will be taken to be the one provided by the Gantt chart.

Activities		Optimistic	Most Likely	Pessimistic
1	Foundation 1	55	60	105
2	Foundation 2	55	60	105
3	Mesostructure 1	172	180	240
4	Mesostructure 2	172	180	240
5	Structure 1	172	180	240
6	Structure 2	200	210	260
7	Masonry	345	360	450
8	Elevators	245	270	350
9	Marbles & Granites	240	270	350
10	Coating	250	270	350
11	Doors	335	360	400
12	Locks & Fittings	335	360	400
13	Cables & Wiring	160	180	240
14	Glass	330	360	400
15	Tableware & Metals	240	270	325

16	Aluminum Profile	510	540	620
17	Façade	405	420	510
18	Basement	690	720	800

Table 6 - Duration Estimates

Since the study of this research is not the construction of simply one condominium but the entire village, hence all 7 condominiums, the following Gantt chart was formulated to depict the construction schedule for the entire Olympic village. As stated earlier all 7 condominiums will be modeled using the same Gantt chart and Network diagram producing the following Gantt chart.

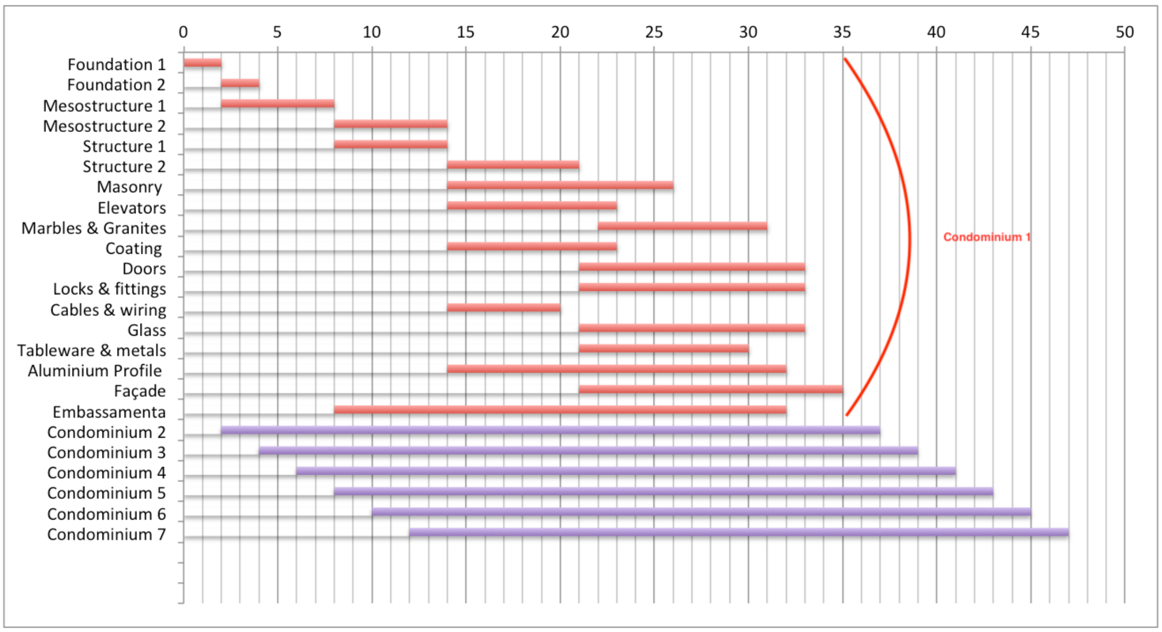


Figure 16 - Gantt Chart for the construction of the Olympic Village

The figure displays the expanded schedule of Condominium 1, followed by the collapsed schedules for the remaining 6 condominiums, as they are all identical. In order to test the overall project construction with all the condominiums the relations between the condominiums had to be defined. The construction of "Foundation 1" for Condominium 2, called "Foundation 2.1" started as soon as "Foundation 1" for Condominium 1 called "Foundation 1.1" is finished, resulting in a Finish-to-Start relation as follows:

Foundation 1.1 **FS** Foundation 2.1

"Foundation 2.1" is then followed by "Foundation 2.2" and continues with the respective activities for the remainder of the condominium. All condominiums have the same FS relations between the respective "Foundation 1" activities.

The overall duration of the project with the overall Gantt chart is 47 months longs as can be seen in the figure including the overall Gantt chart. Assuming 1 month is 4 weeks, the total duration in weeks adds up to 188. Ultimately it is equal to about 3.6

years (188 weeks / 52 weeks/yr), and when looking at the preliminary construction schedule shown in the previous chapter it has the construction of the Olympic and Paralympic village to last 3.5 years starting in June 2012 and ending in December 2015. It is well known and documented in this research that the construction did not start till 2013 and did not finish till mere moments before receiving the first guests in August of 2016.

4.3 Mitigations

When it comes to construction there are several types of mitigations possible, in his book Van Gunsteren recounts some of the mitigations devised by Heerkens (2001), which are stated below:

- Push for compliance.
- Recover in later tasks.
- Add resources.
- Use alternative work methods.
- Offer incentives.
- Renegotiate cost and schedule targets.
- Reduce scope.

In addition to presenting these possible mitigations, there are two vital conditions that need to be fulfilled for successful implementation of the mitigations (Van Gunsteren, 2011):

1. A redundancy of capable people and financial resources has to be available to be assigned to the mitigations.
2. Forthcoming disasters have to be spotted at such an early stage that sufficient time is available for implementation.

In the previous chapter the following three mitigations were identified:

1. Adding skilled workforce
2. Changing contractor
3. Adding concrete accelerating admixture

4.4 Single Condominium Simulations

Before running the simulations on the entire village with all 7 condominiums, first a simulation was run on a single condominium with no mitigations to identify the different paths and critical activities for a single condominium. Additionally as the project is broken up into 7 condominiums, simulations will be run to determine the probability of timely completion of single condominiums followed by simulations to test the overall probability of completion when all 7 condominiums are involved.

The probability of timely completion (within 1040 days) of one condominium with no mitigations is a mere 3.74%. The resulting graph exhibiting the duration in days on the x-axis vs. the Percentage of Timely Completion in percent on the y-axis is displayed next.

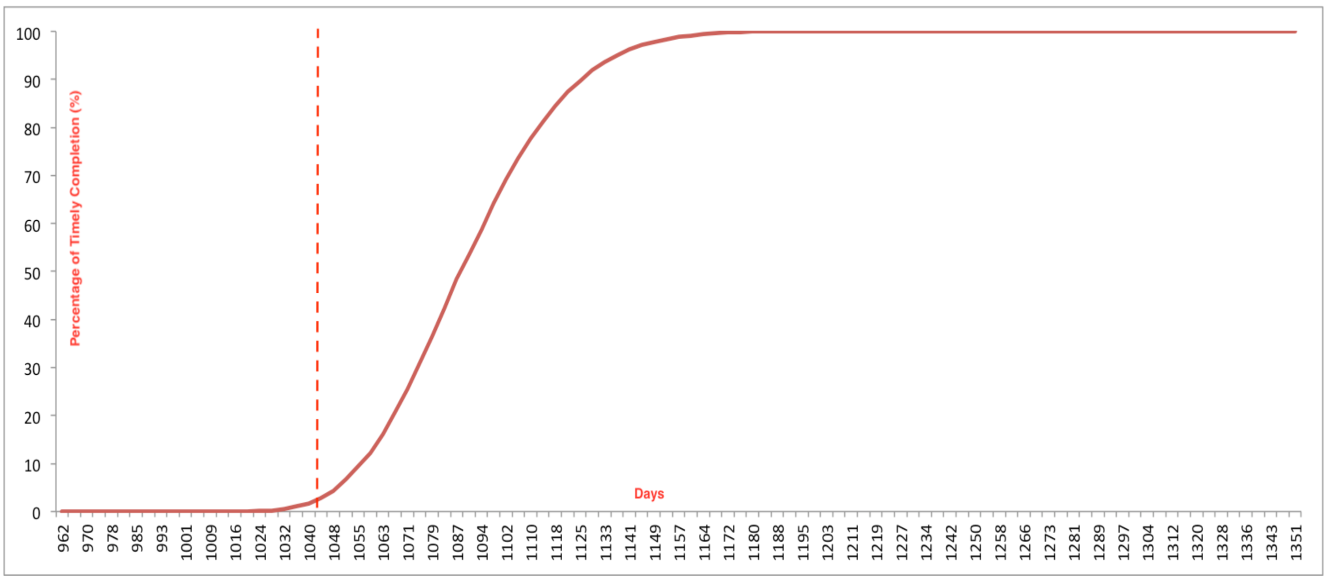


Figure 17 - Percentage of timely completion of one condominium without mitigations

The red dotted line represents the planned deadline of the project. As can be seen in the figure the percentage of timely completion of one condominium without any mitigation within the planned 1040 days is a meager 3.74%.

This low probability can be attributed to the Monte Carlo simulations and the pessimistic estimates used. Due to the lack of skilled workforce mentioned earlier the results could lead to major delays as established in the pessimistic estimate, which lead to the low probability of completion of only 3.74%. Furthermore the PDM software provided information about the number of possible paths and the critical activities on those paths.

There were a total of 13 paths identified, with the following activities labeled as critical activities:

- Foundation 1
- Mesostructure 1
- Structure 1
- Structure 2
- Facade

These activities were identified using the following results sheet.

List of Tasks (Actvities):

Id	Task name	Frm.Dur	Min.Dur	Exp.Dur	Max.Dur	Red.Time	Costs	MCS	Mit	PtF	SfS	St Aft	Fn Bef	Early St	Early Fn	Late St	Late Fn	Tot Flt	Stat	Mode	Frm St	Frm Fn	Act St	Act Fn	Act Dr
1	*Start*	0	0	0	0	0	0.00					0	0	0	0	0	0	0	CRIT	ASAP	0	0			
2	*Finish*	0	0	0	0	0	0.00					0	0	1050	1050	1050	1050	0	CRIT	ASAP	1050	1050			
3	Foundation1	60	55	60	105	0	0.00	S				0	0	0	60	0	60	0	CRIT	ASAP	0	60			
4	Foundation2	60	55	60	105	0	0.00	S				0	0	60	120	990	1050	930	NTCR	ASAP	60	120			
5	Meso1	180	172	180	240	0	0.00	S				0	0	60	240	60	240	0	CRIT	ASAP	60	240			
6	Meso2	180	172	180	240	0	0.00	S				0	0	240	420	870	1050	630	NTCR	ASAP	240	420			
7	Structure1	180	172	180	240	0	0.00	S				0	0	240	420	240	420	0	CRIT	ASAP	240	420			
8	Structure2	210	200	210	260	0	0.00	S				0	0	420	630	420	630	0	CRIT	ASAP	420	630			
9	Masonry	360	345	360	450	0	0.00	S				0	0	420	780	690	1050	270	NTCR	ASAP	420	780			
10	Elevators	270	245	270	350	0	0.00	S				0	0	420	690	780	1050	360	NTCR	ASAP	420	690			
11	Marbles	270	240	270	350	0	0.00	S				0	0	690	960	780	1050	90	NTCR	ASAP	690	960			
12	Coating	270	250	270	350	0	0.00	S				0	0	420	690	510	780	90	NTCR	ASAP	420	690			
13	Doors	360	335	360	400	0	0.00	S				0	0	630	990	690	1050	60	NTCR	ASAP	630	990			
14	Locks	360	335	360	400	0	0.00	S				0	0	630	990	690	1050	60	NTCR	ASAP	630	990			
15	Cables	180	160	180	240	0	0.00	S				0	0	420	600	870	1050	450	NTCR	ASAP	420	600			
16	Glass	360	330	360	400	0	0.00	S				0	0	630	990	690	1050	60	NTCR	ASAP	630	990			
17	Tableware	270	240	270	325	0	0.00	S				0	0	630	900	780	1050	150	NTCR	ASAP	630	900			
18	Aluminum	540	510	540	620	0	0.00	S				0	0	420	960	510	1050	90	NTCR	ASAP	420	960			
19	Facade	420	405	420	510	0	0.00	S				0	0	630	1050	630	1050	0	CRIT	ASAP	630	1050			
20	Basement	720	690	720	800	0	0.00	S				0	0	240	960	330	1050	90	NTCR	ASAP	240	960			

Figure 18 - Critical/Not Critical Activities

As can be seen in the figure above, the activities within the red boxes are the critical ones, denoted as "CRIT" by the PDM software and having a float of 0. This helps us identify which activities to give better attention to and possibly apply mitigation on. The identified mitigations are represented in the following table along with their duration reduction and costs.

Critical Activity	Mitigation	Reduced Duration	Cost
Foundation 1	Concrete Admixture	14	$200,000
Mesostructure 1	Added Workforce	21	$400,000
Structure 1	Change Contractor	14	$500,000
Structure 2	Change contractor	21	$500,000
Facade	Added Work Force	28	$750,000

Table 7 – Mitigations

The PDM software is able to register a maximum of 15 mitigations; this means it is important to find the best combination with the least mitigations that will provide a probability of timely completion to satisfy the 50% threshold. Through testing the numerous mitigations and combinations it was found that a single mitigation by itself is not enough to reach the 50% threshold, so the combinations of 2 mitigations at a time were tested with the following results:

Combination Number	Activity	Cost ($)	Total Cost ($)	Probability of Timely Completion
1	Foundation 1	200,000	700,000	29.80 %
	Structure 1	500,000		
2	Structure 1	500,000	1,000,000	39.72 %
	Structure 2	500,000		
3	Foundation 1	200,000	700,000	39.76 %
	Structure 2	500,000		
4	Foundation 1	200,000	600,000	40.08 %
	Mesostructure 1	400,000		
5	Mesostructure 1	400,000	900,000	40.08 %
	Structure 1	500,000		
6	Structure 1	500,000	1,250,000	49.80 %
	Facade	750,000		
7	Foundation 1	200,000	950,000	49.88 %
	Facade	750,000		
8	Mesostructure 1	400,000	900,000	50.31 %
	Structure 2	500,000		
9	Structure 2	500,000	1,250,000	57.24 %
	Facade	750,000		
10	Mesostructure 1	400,000	1,150,000	59.39 %
	Facade	750,000		

Table 8 – Mitigation Combinations

Looking at the table above, it shows 3 combinations that satisfy the 50% threshold. Combinations 9 and 10 produce a 57.24% and 59.39% timely completion respectively, but the combination that will be chosen is Combination 8 despite it only producing a 50.31% timely completion. Combination 8 is chosen because it is the cheapest option that satisfies the 50% threshold. The next figure depicts the simulation results using combination 8 of the mitigations.

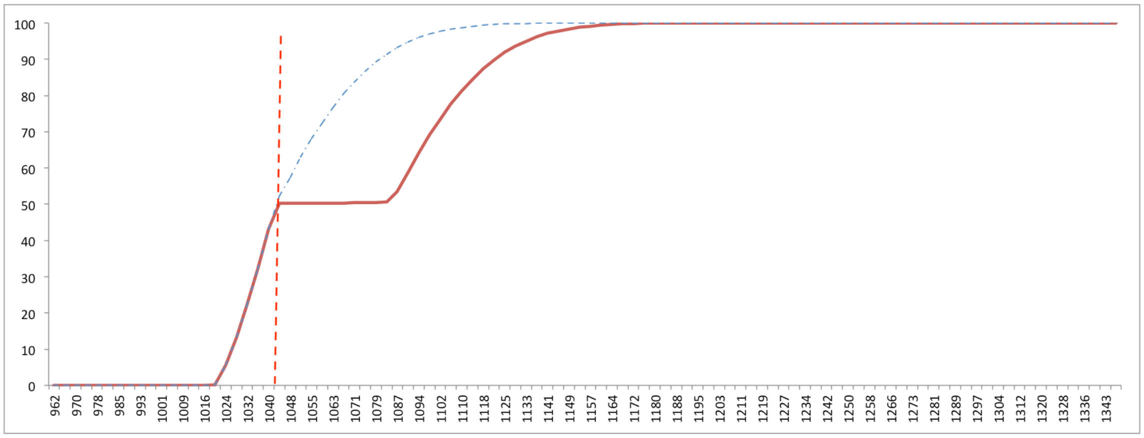


Figure 19 - Percentage of Timely Completion for one Condominium with Mitigations

The rise in probability of timely completion within the given duration rises considerably from 3.74% to 50.31%. The red graph represents the results only including the feasible mitigations, while the dashed blue graph represents the graph for all mitigations (feasible and infeasible). The break in the red graph is due to the fact that after the deadline (vertical line) the mitigations are deemed infeasible as timely completion is not achieved and hence their affect on timely completion is neglected and left out of the graph.

4.5 Simulations with Status Adjustment For Single Condominium

Five simulations will be carried out to study the difference it makes when a significant part of construction is done and activity durations become known. For each simulation the results will be shown graphically by plotting the Percentage of Timely Completion vs. the Project Duration as shown earlier. Additionally, since the research is not just about completing the project on time, but also to balance out the costs in order to avoid the unbalanced spending, hence the rise in costs at the end to amend the problems and delays faced, a graph will show the weekly cost of construction including mitigations that satisfy the 50% timely completion threshold.

4.5.1 Simulation at 0% Completion

This simulation is done at the beginning of the project with all activities represented as the estimates represented in the previous table. At 0% completion, the outcome is the same as the one presented earlier as no activities have been executed yet.

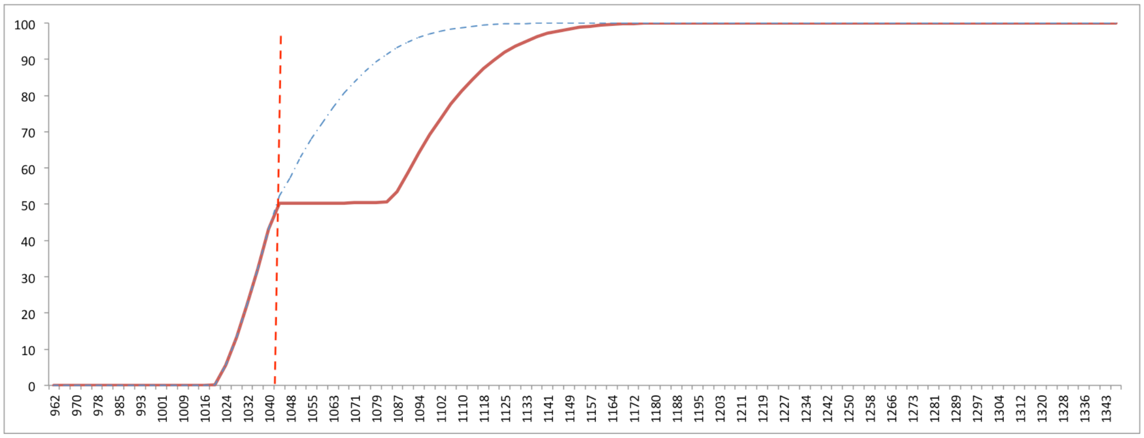


Figure 20 - Percentage of Timely Completion of one Condominium at 0%

With mitigation combination 8 (Mesostructure 1 – Added Work Force & Structure 2 – Change of Contractor) chosen, the overall weekly costs of construction of one condominium are displayed below.

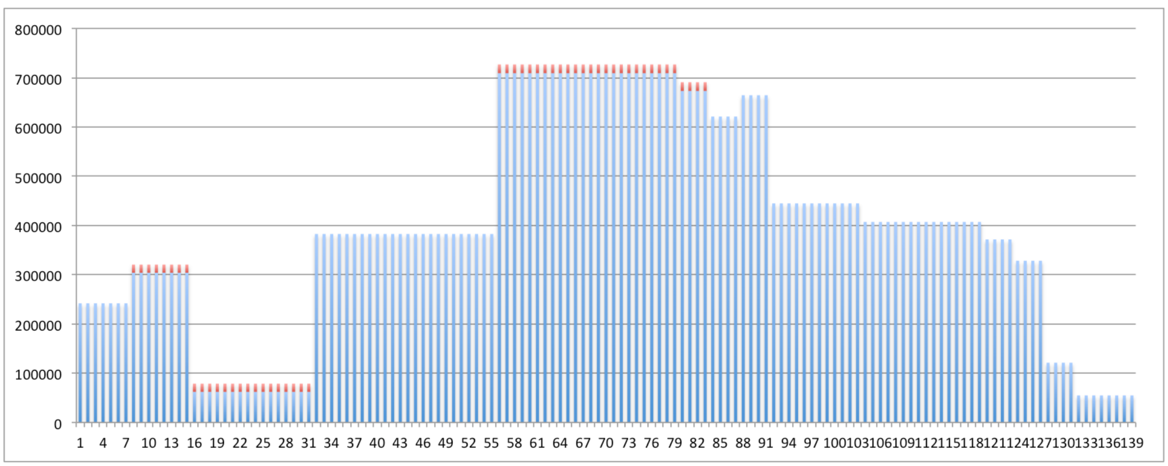


Figure 21 - Weekly Costs of Construction for one Condominium including Mitigations

Costs per week are posted on the y-axis while the x-axis represents the number of week. The blue bars represent the average cost per week of construction. This value was deduced from taking the average cost of each activity over the seven condominiums. The red bars are the additional costs, which are the mitigation costs.

4.5.2 Simulation at 20% Completion

After 20% of the construction is complete the graph of probability of timely completion vs. duration looks as follows:

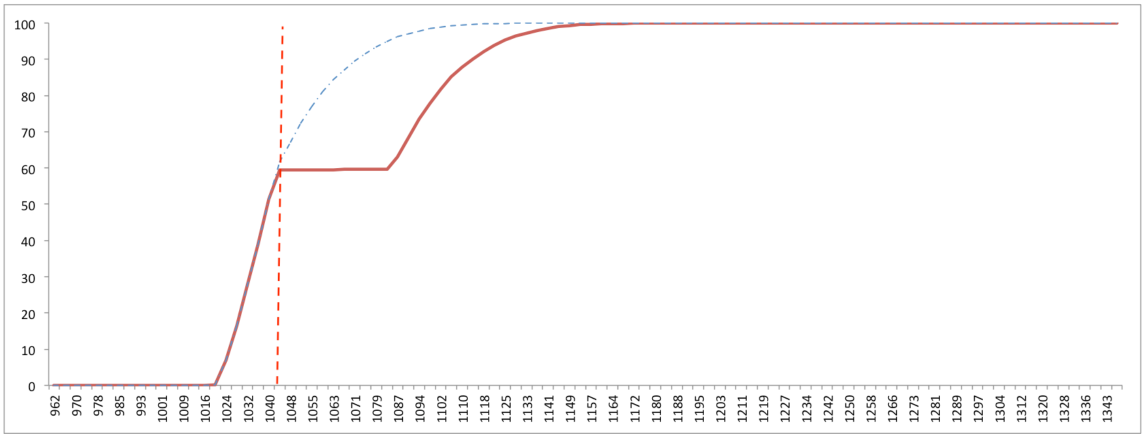


Figure 22 - Percentage of Timely Completion of one Condominium at 20%

Probability of timely completion rose from 50.31% to 59.54% due execution of some of the activities prior to the 20% completion mark, leading to less total uncertainty.

4.5.3 Simulation at 40% Completion

After 40% of the construction is complete the graph of probability of timely completion vs. duration looks as follows:

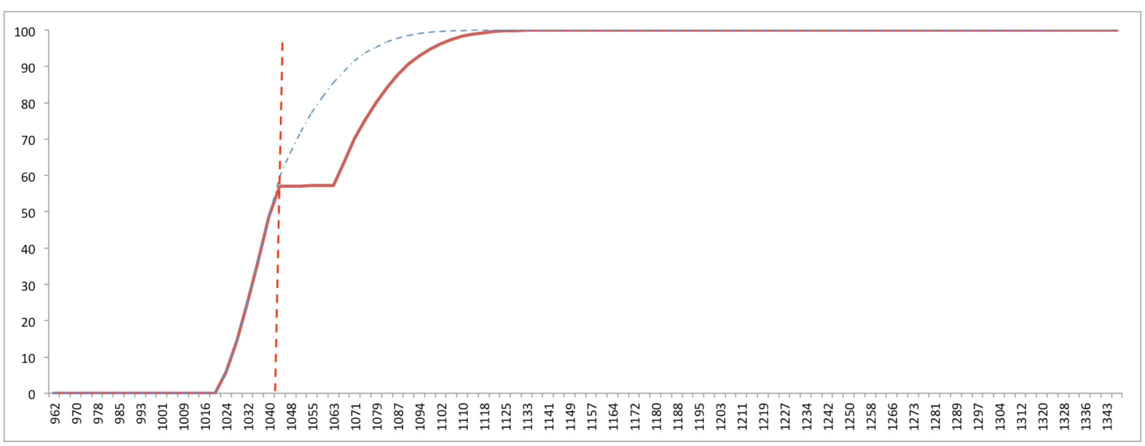


Figure 23 - Percentage of Timely Completion of one Condominium at 40%

Probability of timely completion dropped from 59.54% to 56.99%. This drop in percentage of timely completion can be attributed to the fact that after 40% of construction is completed the Mesostructure activity which has the first mitigation attributed to it is already done and hence leaving the project with only one mitigation incase problems happen, hence lowering the percentage of timely completion. Despite the lower percentage of timely completion, it still satisfies the 50% threshold.

4.5.4 Simulation at 60% Completion

After 60% of the construction is complete the graph of probability timely completion vs. duration looks as follows:

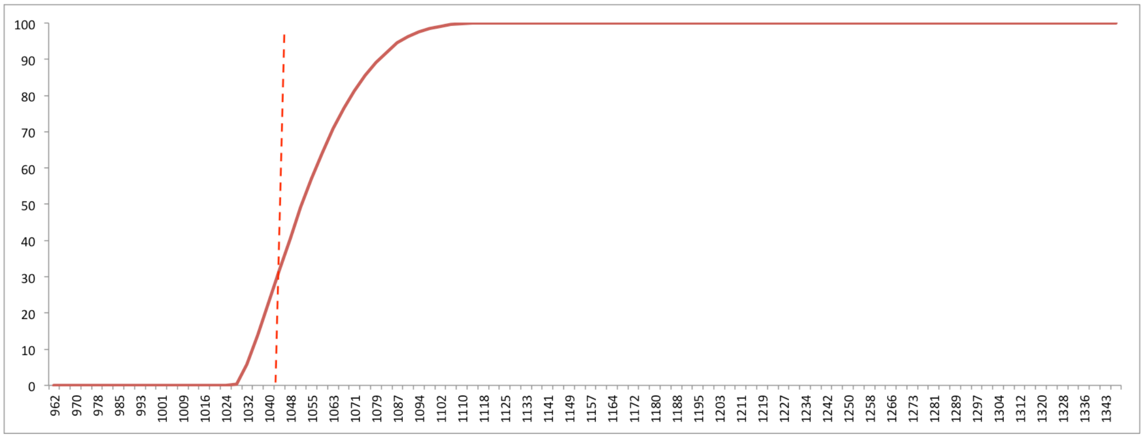


Figure 24 - Percentage of Timely Completion at 60% Completion

For this simulation the probability of timely completion drops drastically from 56.99% to an unacceptable 31.82%. As for before, this drop can be attributed to the fact that there are no mitigations remaining at this point in time in construction so if delays occur and activities take longer than required, which they will; given the high pessimistic estimates given, the project will be delayed and not finish on time.

In the initial simulation with no mitigations, five critical activities were identified with only one remaining at this point in time of construction. This activity is the Façade activity. When applying the identified mitigation of adding more workforces resulting in a 28-day duration reduction and a cost of $750,000, the 50% threshold is re-instated and construction has a probability of 80.02% timely completion. This result is relatively high, which is attributed to the fact that more than half of the construction is completed with only one critical activity remaining, which is the Façade activity to which a mitigation has just been assigned. The new graph with the added mitigation looks as follows:

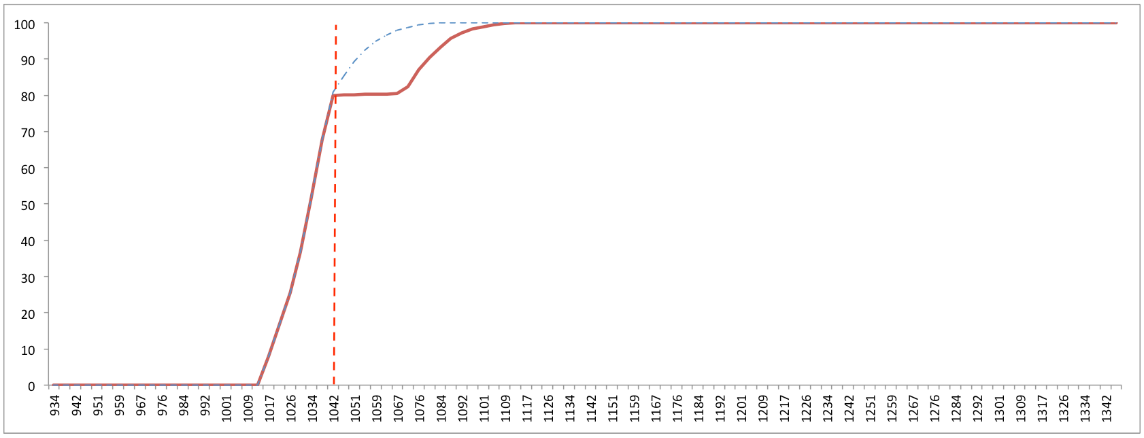


Figure 25 - Percentage of Timely Completion at 60% Completion (With Additional Mitigation)

As stated earlier, this results in an additional cost of $750,000, which will be divided equally along the duration of the Façade activity, and will furthermore produce the following weekly cost graph.

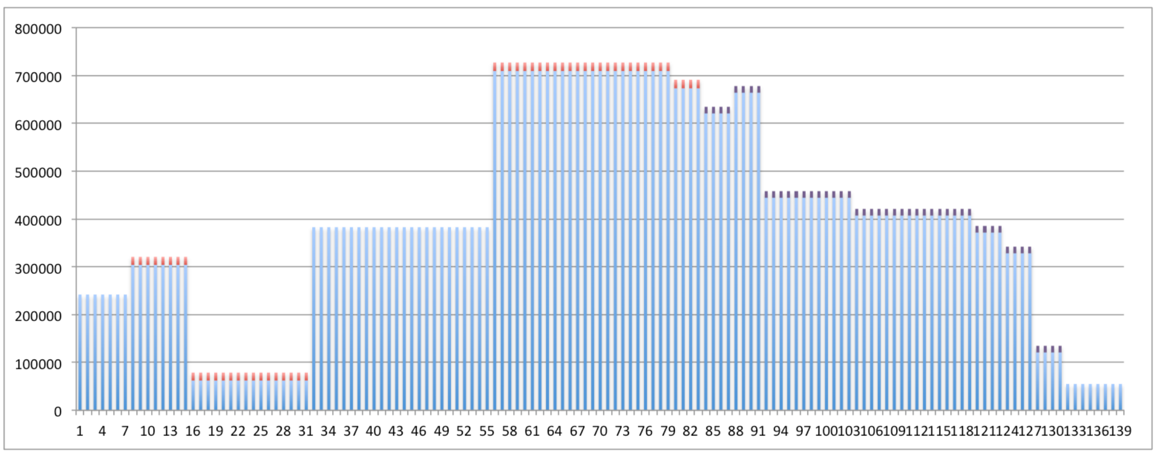


Figure 26 - Weekly costs of Construction for one Condominium including Mitigations (Updated)

The figure is updated from the previous weekly cost graph in the fact that the purple bars indicate the added costs of the mitigation assigned to the Façade activity amounting to a total of $750,000.

4.5.5 Simulation at 80% Completion

After 80% of the construction is complete the graph of probability of timely completion vs. duration looks as follows:

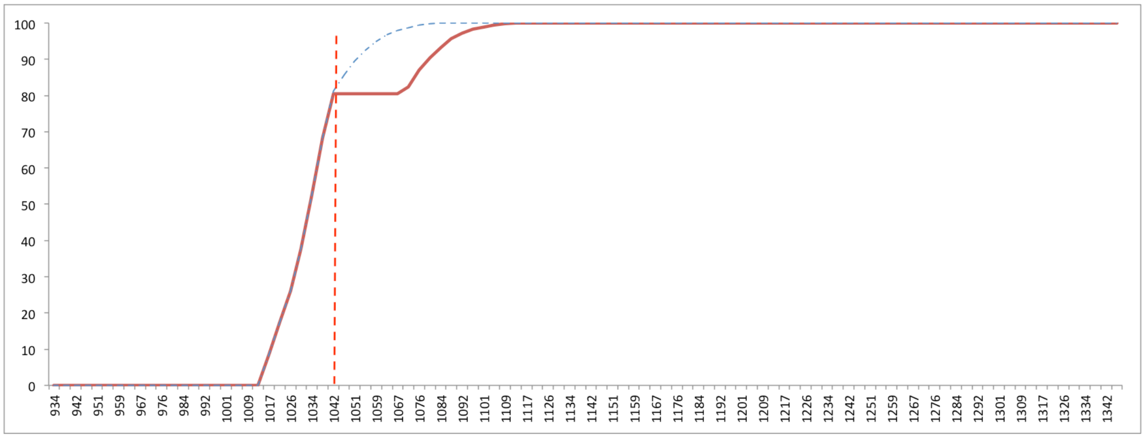


Figure 27 - Percentage of Timely Completion at 80% Completion

With no critical activities remaining and only 20% of construction left there is little room for change; therefore the probability of timely completion at 80% completion is almost identical to the one before with a completion probability of 80.44%.

4.6 Simulations for Entire Village (7 Condominiums)

When looking at the construction of the entire village, simulations will differ. There exist 7 condominiums that need to be built, each in succession of the other and related only through the first activity, namely Foundation 1. With the completion of Foundation 1.1 (Foundation 1 for condo 1), then Foundation 2.1 (Foundation 1 for condo 2) can start and so forth. This means the only critical activity between condominiums is the Foundation 1.

First, as was done for the single condominium before, a simulation without any mitigation is done for the entire village. The probability of timely completion (within 1410 days) without mitigations for the entire village is 0.11%.

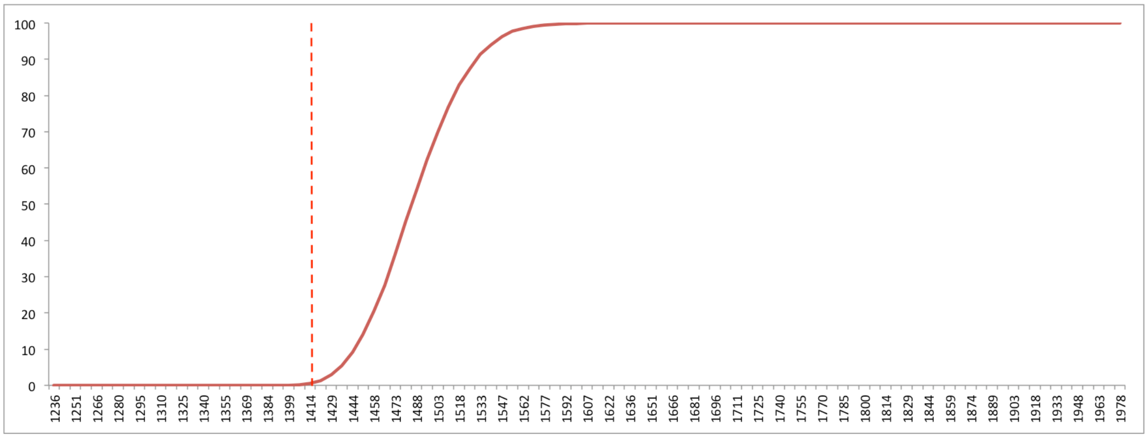


Figure 28 - Percentage of Timely Completion of Entire Village without Mitigations

From the first simulation it was confirmed that the "Foundation 1" activities for all the 7 condominiums are critical activities. Additionally, four more activities were identified as critical, all of which are activities from the last condominium (condo 7). These activities were the: Mesostructure 1, Structure 1, Structure 2 and finally Façade. These are the same activities identified in the earlier simulation for the single condominium. This time they are only critical in the last condominium. This is caused by the fact that the critical path for the entire village is as follows:

Foundation 1.1 –> Foundation 2.1 –> Foundation 3.1 –> Foundation 4.1 –> Foundation 5.1 –> Foundation 6.1 –> Foundation 7.1 –> Mesostructure 7.1 -> Structure 7.1 –> Structure 7.2 –> Façade 7

Only the last condominium has the named activities marked as critical as the 6 previous condominium activities have enough time, even with delay to finish as they have time all the way till the end of the deadline, while on the other hand, the last condominium to which the additional mitigations were assigned only has a limited time as it is the last condominium to start construction, with the shortest lead time to the deadline. As the point is to choose the least number of mitigations to reach the 50% threshold the first simulation will start off with 7 mitigations, all assigned to the respective "Foundation 1" activities for each condominium. The mitigation assigned to the "Foundation 1" activity is Adding Concrete Admixture, resulting in a duration reduction of 14 days at a cost of $200,000, as stated in the mitigations table earlier in this chapter.

4.7 Simulations with Status Adjustment Results For Entire Olympic Village

As was done before for the single condominium, five simulations will be carried out to study the difference it makes when a significant part of construction is done and activity durations become known.

4.7.1 Simulation at 0% Completion

This simulation is done at the beginning of the project with all activities represented as the estimates represented in the previous table.

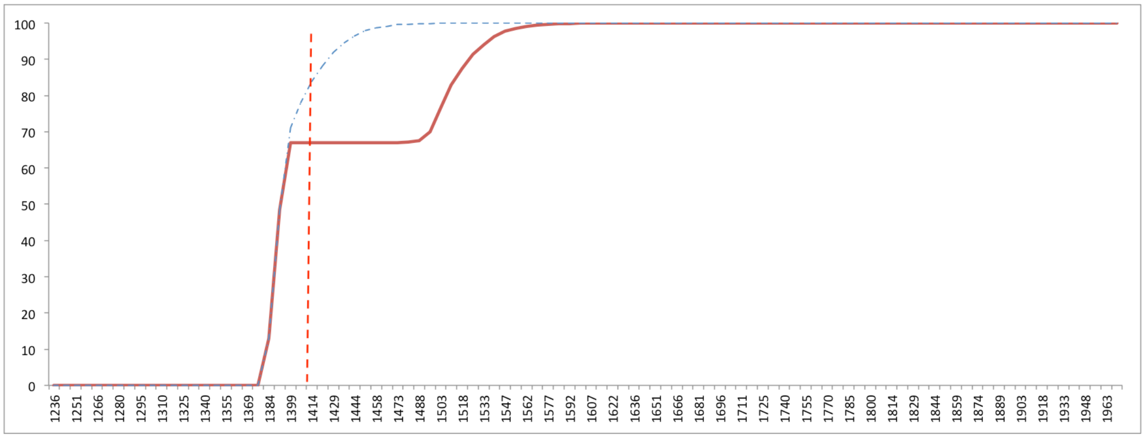


Figure 29 - Percentage of Timely Completion of Entire Olympic Village at 0% Completion

As was the case for the single condominium simulations, here too the red graph represents the graph for feasible mitigations, while the blue one represents all (feasible and infeasible). As explained earlier the break in the red graph is due to the fact that the mitigations after the vertical line set at the deadline are infeasible mitigations and their effect on timely completion is neglected, while the blue graph prior to the vertical line represents the effect it would have to have all mitigations running, which is not the case for our simulations as our aim is to reach the 50% threshold. Percentage of timely completion at 0% completion with the assigned mitigations on "Foundation 1" activities rises from 0.11% to 67.04%. This result is achieved by using mitigations on all 7 "Foundation 1" activities of the village. If we leave the mitigation out for one of the "Foundation 1" activities, the probability of timely completion drops to 51.11% and still satisfies the 50% threshold while using the least number of mitigations namely 6. The graph below depicts the weekly cost of construction for the entire village including the aforementioned mitigation applied on all 7 condominiums, except the first.

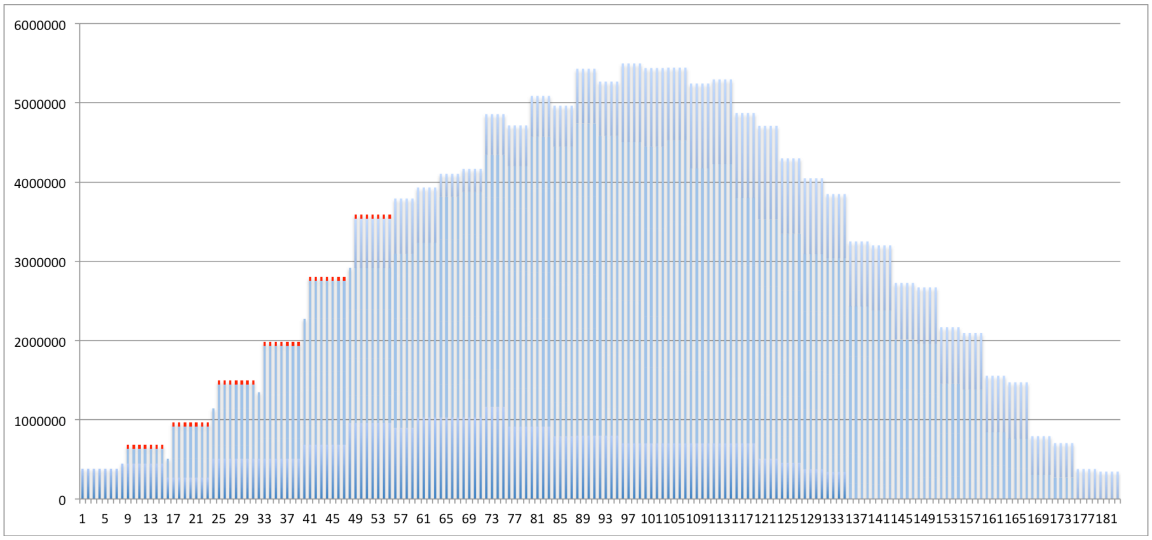


Figure 30 - Weekly Construction Costs of Entire Olympic Village Including Mitigations

As with the single condominium before, the blue bars in the figure depict the cost of construction of the 7 condominiums, while the red bars indicate the additional costs due to mitigations.

4.7.2 Simulation at 20% Completion

After 20% of the construction is complete the graph of probability timely completion vs. duration looks as follows:

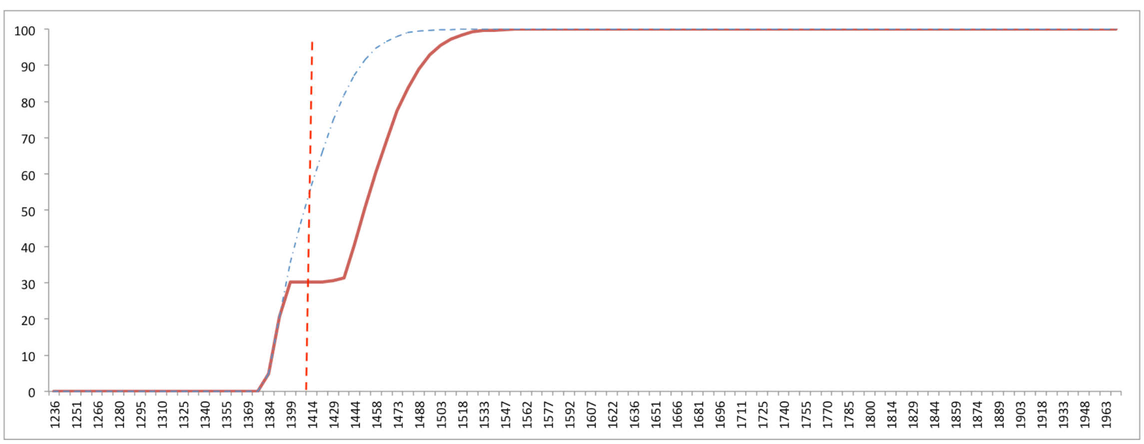


Figure 31 - Percentage of Timely Completion of Entire Olympic Village at 20% Completion

The percentage of timely completion has dropped from an acceptable 51.11% to an unacceptable 30.17%. This can be attributed to the large uncertainty in the remaining tasks in condominium 7 that have yet to be assigned mitigations, as it was not needed earlier. Furthermore, the earlier percentage of timely completion of 51.11% is only for overall completion of the entire project, meaning condominium 1 could have delayed significantly given there are no additional mitigations as was the case for the single condominium simulations with 3 mitigations, leading to less time for the following condominiums to finish, hence the lower percentage of timely completion. Applying an additional mitigation can amend the result of 30.17% timely completion. By applying the Added Workforce mitigation on Mesostructure 7.1, reducing the duration by 21 days and costing $400,000, the percentage of timely completion rises to an acceptable 55.85% as can be seen in the figure below.

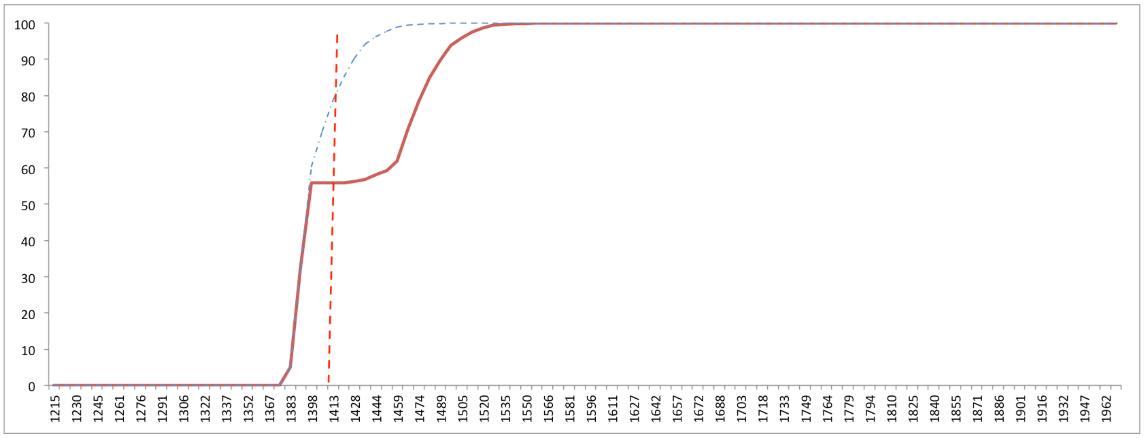


Figure 32 - Percentage of Timely Completion of Entire Olympic Village at 20% Completion (With Additional Mitigation)

The added mitigation helps us acquire the required 50% threshold, but also adds a little bit of cost to the weekly construction costs resulting in the following cost graph.

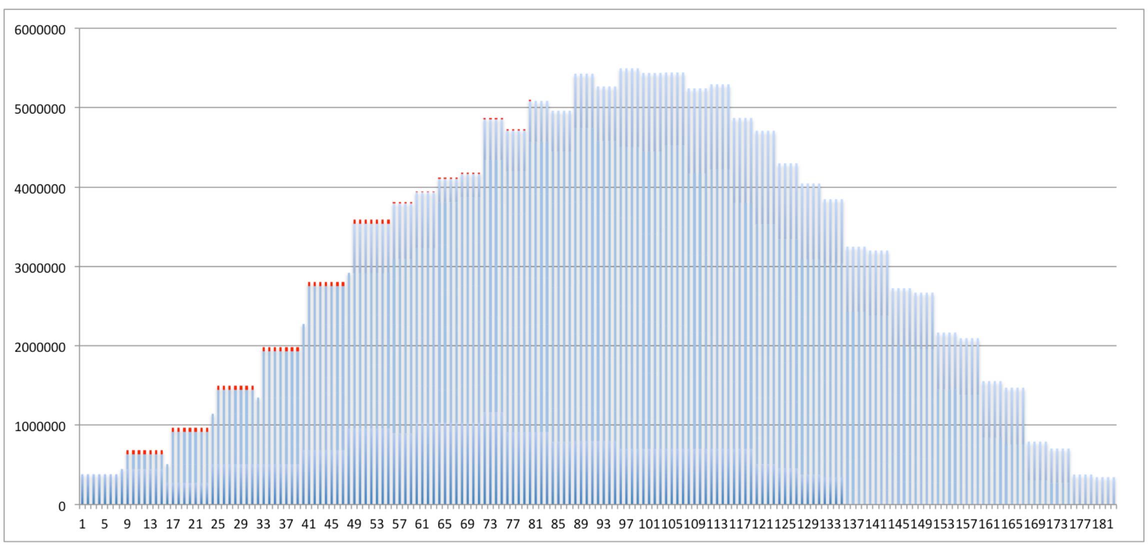


Figure 33 - Weekly Construction Cost of Entire Olympic Village including Mitigations (Updated)

The effect on the weekly cost graph might seem small, but the effect this additional cost has on the percentage of timely completion is huge.

4.7.3 Simulation at 40% Completion

After 40% of the construction is complete the graph of probability timely completion vs. duration looks as follows:

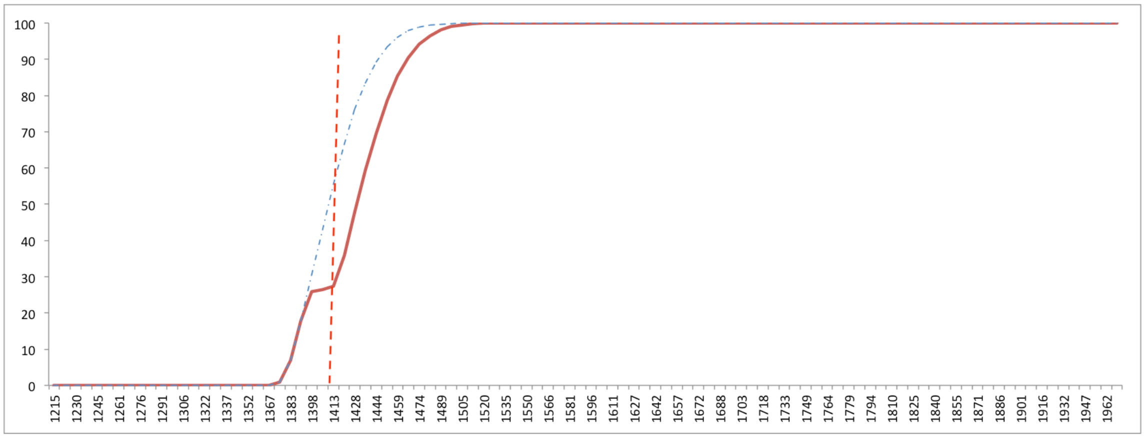


Figure 34 - Percentage of Timely Completion of Entire Olympic Village at 40% Completion

Again percentage of timely completion drops from 55.85% to 26.04%. The means an additional mitigation is required at this stage. The mitigation added changing the contractor for Structure 7.2, resulting in an increase of probability of timely completion to an acceptable 55.07% as shown in the figure below.

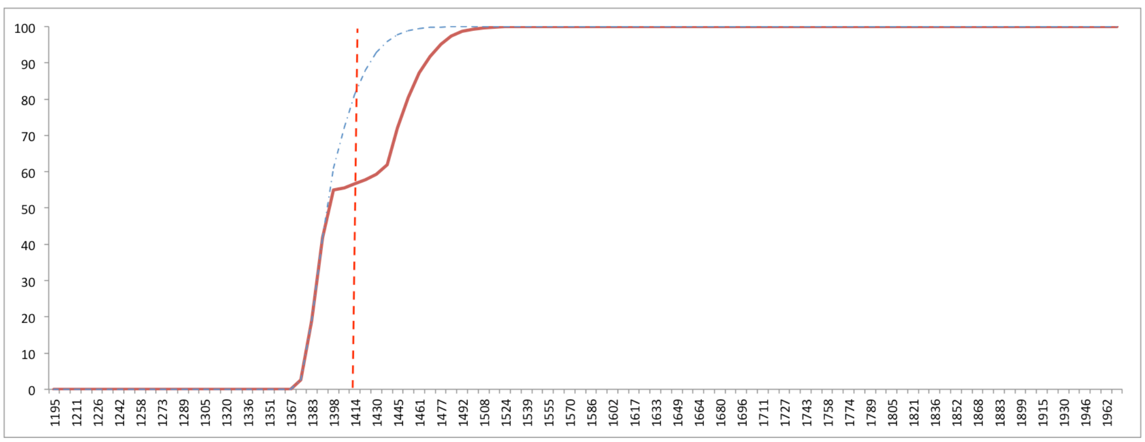


Figure 35 - Percentage of Timely Completion of Entire Olympic Village at 40% Completion (With Additional Mitigation)

The additional mitigation will also bring along additional costs, which are reflected in the weekly cost graph that follows.

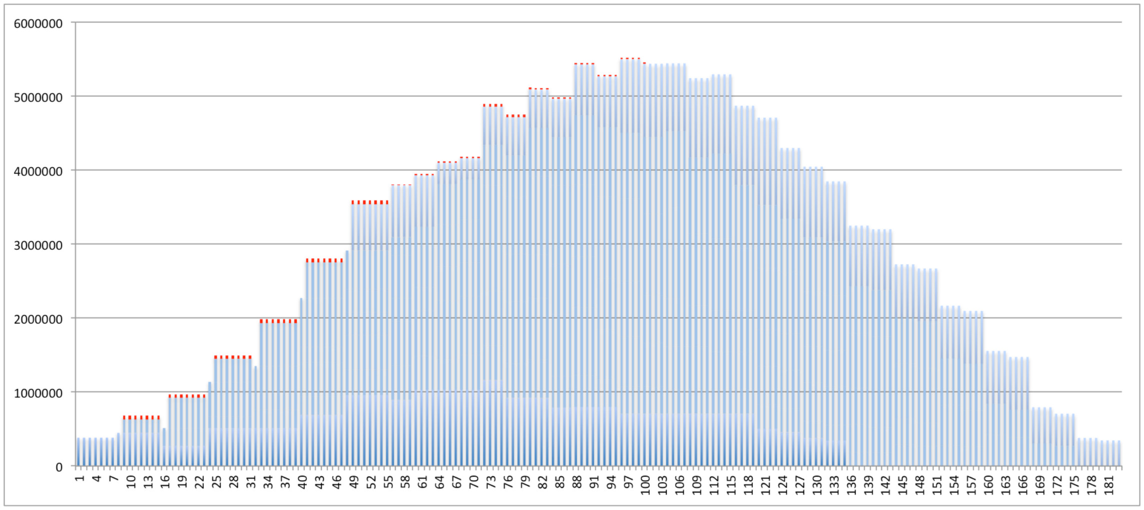


Figure 36 - Weekly Construction Cost of Entire Olympic Village including Mitigations (Update Number 2)

4.7.4 Simulation at 60% Completion

After 60% of the construction is complete the graph of probability timely completion vs. duration looks as follows:

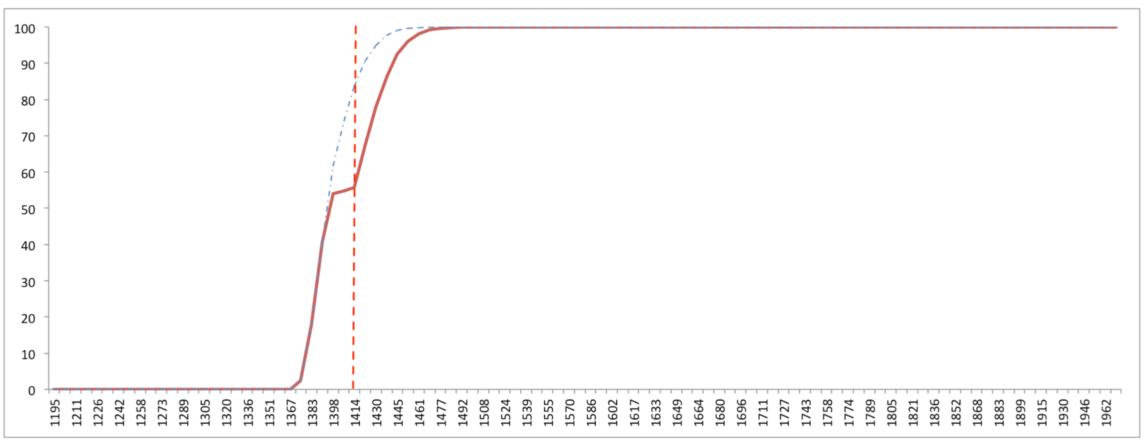


Figure 37 - Percentage of Timely Completion of Entire Olympic Village at 60% Completion

The probability of timely completion at 60% completions is an acceptable 54.28%, which means that no additional mitigations are needed at this stage in the project.

4.7.5 Simulation at 80% Completion

After 80% of the construction is complete the graph of probability timely completion vs. duration looks as follows:

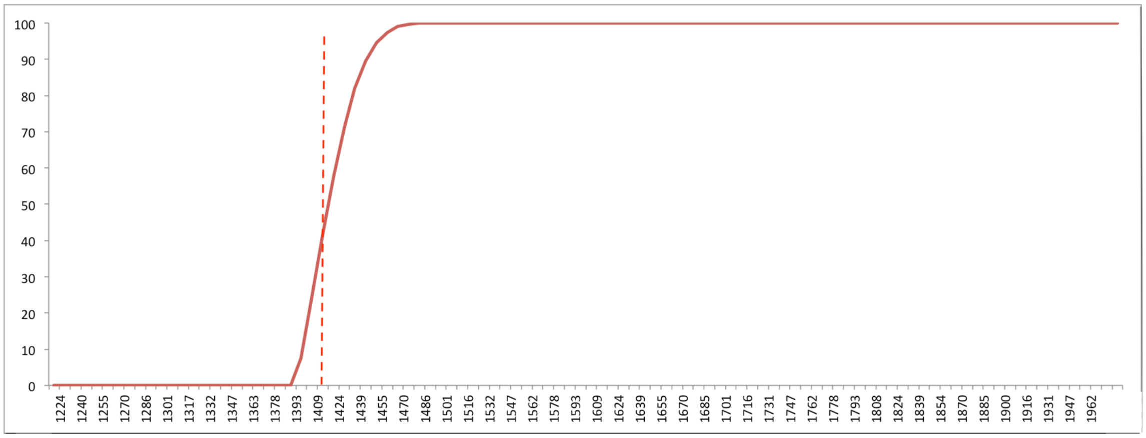


Figure 38 - Percentage of Timely Completion of Entire Olympic Village at 80% Completion

The drop in percentage of timely completion from 54.28% to 41.61% as can be seen in the figure above is fixed by adding the last and final mitigation on the Façade activity of Condominium 7 (Added Work Force, Duration Reduction 28 days, Cost = $750,000).

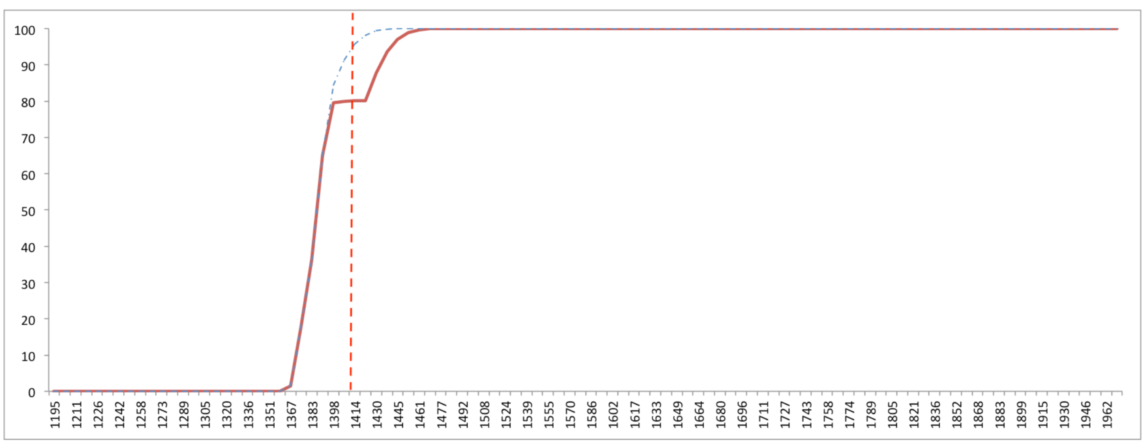


Figure 39 - Percentage of Timely Completion of Entire Village at 80% Completion (With Additional Mitigation)

This improves the probability of timely completion from 41.61% to an acceptable 79.66%. This also adds some costs to the weekly cost graph as can be seen below.

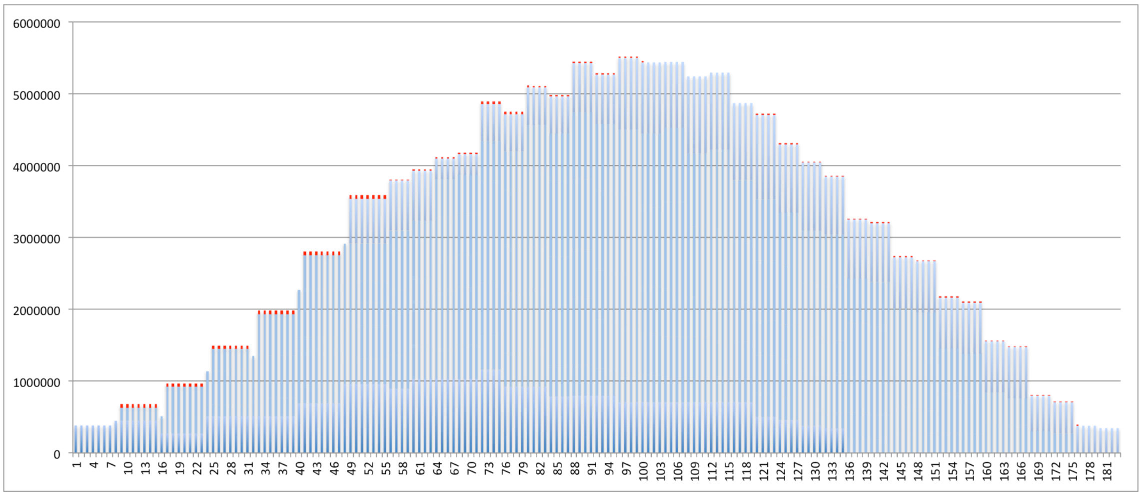


Figure 40 - Weekly Construction Cost of Entire Olympic Village Including Mitigations (Final Update)

4.8 Analysis of Results

Looking at the results for both single condominium and the entire Olympic village, it is evident that the Mitigation Planner and the PDM software have had a significant effect on both the percentage of timely completion, which for an event with a fixed deadline like the Olympics Games is of vital importance. Furtherer more the simulations and added mitigations make sure that spending is more uniformly spread over the entire project rather than having a spike in costs at the end stages to make up for the delays.

The percentages of timely completion which were a miserably 3.74% for the single condominium and 0.11% for the entire village, without mitigations, were both brought up to above the 50% threshold through the use of certain mitigations. Using the “Percent Completion” option featured in the PDM software allowed for simulations into the future, making it possible to simulate construction with activities already completed to see how it affects the future outcome of timely completion. This technique made sure that through out the entire project the project managers know what activities to focus on, and to which activities to assign mitigations.

The results of the simulations for both single condominium and the entire village are posted in the following two tables respectively.

% Completion	Probability of Timely Completion		
	Without Mitigations	**With Mitigations**	**Mitigation Used**
0%	3.74%	50.31%	M1 S2
20%	6.35%	59.54%	M1 S2
40%	17.48%	56.99%	M1 S2
60%	28.35%	31.82% (80.02%)	M1 S2 (Fac)
80%	28.52%	80.44%	M1 S2 Fac

Table 9 - Evolution of Probability of Timely Completion as construction progresses (Single Condominium)

M1 – Mitigation on Activity Mesostructure 1 (Add Work Force)
S2 – Mitigation on Activity Structure 2 (Change Contractor)
Fac – Mitigation on Activity Façade (Add Work Force)

% Completion	Probability of Timely Completion		
	Without Mitigations	**With Mitigations**	**Mitigations Used**
0%	0.11%	51.11%	6xF1
20%	1.08%	30.17% (55.85%)	6xF1 + (M7.1)
40%	5.68%	26.04% (55.07%)	6xF1 + M7.1 + (S7.2)
60%	17.06%	54.28%	6xF1 + M7.1 + S7.2
80%	27.15%	41.61%(79.66%)	6xF1 + M7.1 + S7.2 + (Fac7)

Table 10 - Evolution of Probability of Timely Completion as construction progresses (Entire Olympic Village)

6xF1 – Mitigation on Activity Foundation 1 (6 times Foundation 1) (Add Concrete Admixture)
M7.1 – Mitigation on Activity Mesostructure 7.1 (Add Work Force)
S7.2 – Mitigation on Activity Structure 7.2 (Change Contractor)
Fac7– Mitigation on Activity Façade 7 (Add Work Force)

The percentages inside the brackets represent the updated percentages of timely completion, after initial simulations with the previous assigned mitigations have produced results below the 50% threshold, which can be seen outside the brackets. These "updated" simulations have the newly added mitigation also written in brackets in the following column of the table.

Starting of at 3.74% timely completion and rising to 50.31% with the addition of only 2 mitigations, and ultimately reaching to 80.44% timely completion at 80%

completion of construction while adding a third and final mitigations are promising results that the construction of a single condominium would finish on time and without extreme cost overruns at the end of the project. The same goes to the construction of the entire village which started of with a 0.11% timely completion at 0% completion with no mitigations straight to 51.11% with the addition of only 1 mitigation to 6 of the 7 condominiums, and ultimately reaching 79.66% timely completion at 80% completion of construction with a total of 9 mitigations.

The results can help the project managers of the single condominium identify the critical paths and critical activities to focus on and prepare mitigations for. On the other hand the results of the entire village can help the project manager with the overall project management; all 7 condominiums together, to manage the entire construction of the village as a whole. The results have shown that to assure timely completion of the entire village, the most important condominium is the last, to which 4 mitigations are assigned; the same ones assigned to the simulations in the single condominium, excluding the "Foundation 1" mitigation.

The results of the simulations on the entire village do not even include the mitigations on each single condominium as the number of mitigations (28) would be too large to input into the software (Software limit = 15 Mitigations), yet with the limited number of mitigations used (9), results were acquired that exceed the required 50% threshold. Theoretically, if the mitigations assigned to the single condominium simulations were to be assigned to the simulations of the entire village, percentage of timely completion would increase significantly, notwithstanding the already satisfying results.

4.8.1 Single Condominium Costs

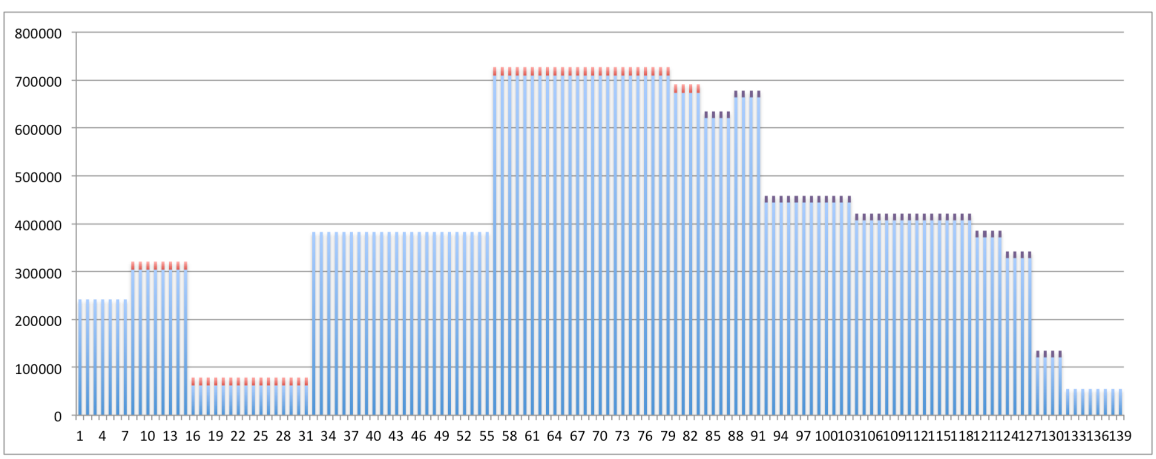


Figure 41 - Final Weekly Construction Cost for Single Condominium including Mitigations

Added mitigations mean added costs, but the results show that the statements made earlier in this research about spending more early rather than later would benefit the project. Looking at the single condominium, the total combined cost of the three mitigation assigned amounts to $.1.65 million, spread out evenly across the entire project. The average cost of construction of a single condominium was $75.75 million. Comparing the added cost of $1.65 million to the average overall cost of construction, it amounts to 2.18%. Spending only 2.18% of the total construction cost of a single condominium on the mitigations assigned, with the help of the PDM software, raises the percentage of timely completion from 3.74% to at least 50.31%.

4.8.2 Entire Olympic Village Costs

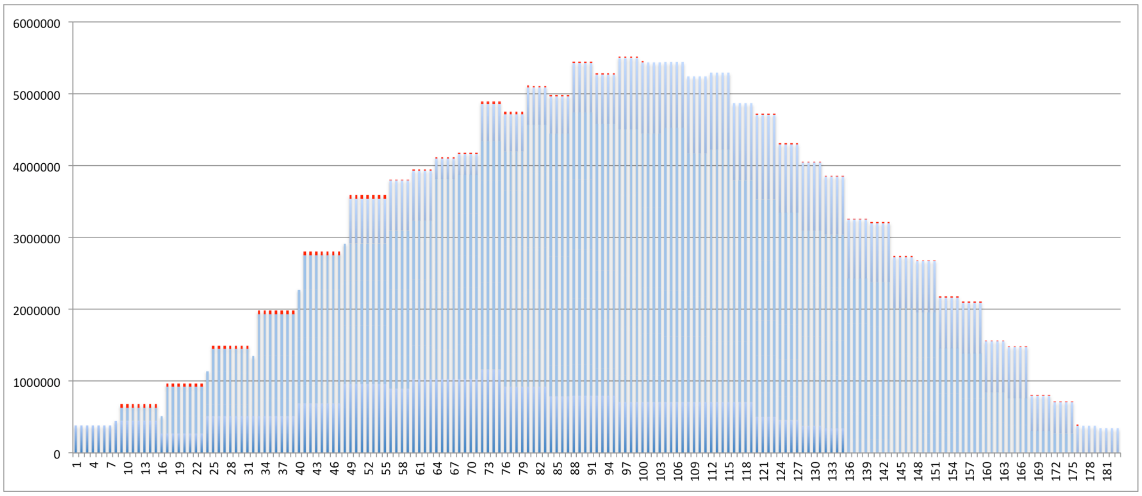


Figure 42 - Final Weekly Construction Cost for Entire Olympic Village including Mitigations

The overall cost of all the 7 condominiums amounted to around $558 million. The mitigations used in the simulations amount to an overall added cost of $ 2.85million; 0.51% of the overall construction cost. Only 0.51% of the construction cost would raise the percentage of timely completion from 0.11% to at least 51.11%, not considering the possibility of having to add all the mitigations that were identified for each condominium. If that were the case, then the overall cost for the added mitigations would be $12.75 million; 2.28% of overall construction cost. In chapter 3 it indicates that the construction managers would assign an additional 4% margin of construction cost on each condominium, with some buildings reaching 6% and 7%. Both scenarios; the tested one with the 9 mitigations (0.51% of total construction cost), and the theoretical one with 28 mitigations (2.28% of total construction cost), have a lower percentage of additional costs, while maintaining an equally spread out spending agenda.

The way the mitigations are placed, while also achieving required results helps maintain the well spread out structure of costs in comparison to the drastic rise in cost that can be seen in graph of the Planned costs vs. Actual costs presented below.

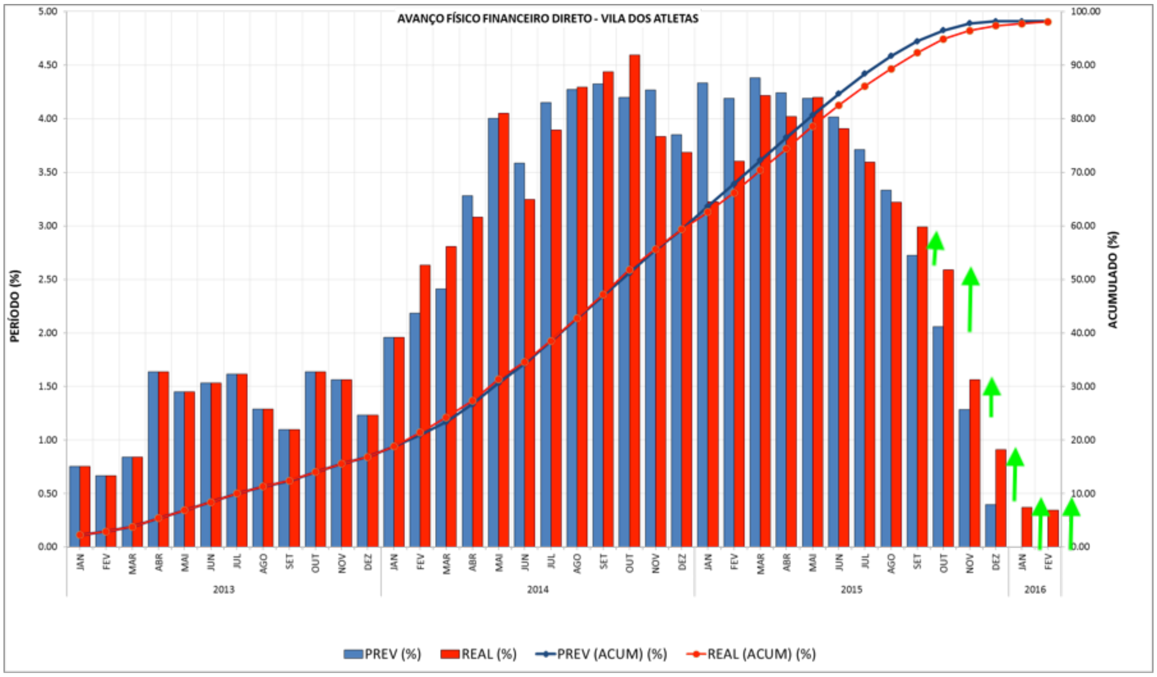


Figure 43 - Planned vs. Actual Costs (Acquired from and adjusted: Ilha Pura, (2017). Da construcao ao legado)

It is evident that the final 6 months have higher actual costs (red bars) than planned costs (blue bars), not to mention the months after February that cannot be seen on the graph, and to which interviews have confirmed what the media says, that construction did not finish till well into the summer of 2016. This imbalance in spending could have been avoided had the Mitigation Planner been used as a planning tool, helping to identify critical paths, critical activities and possible/feasible mitigations. Making decisions early and spending on mitigations early rather on lost time later has also proven to be better for timely completion as the previous sections have shown.

5. Conclusion and Recommendations

This final chapter will give a conclusion about the results of this research, and some recommendations based on the results. At the beginning of this research it was stated that the objective was to show how the Mitigation Planner could help provide better planning and control over project activities to avoid the time squeeze faced in organizing the Olympics, with the following research question asked:

"Can the Mitigation Planner prevent the unbalanced spending in organizing the 2016 Rio Olympic games?"

The results of the simulations and the corresponding cost graphs show that the answer to this question is a clear Yes! Comparing the rise in unplanned costs at the end of construction from the graph depicting the actual cost vs. planned cost to the way the cost of mitigations were spread out over the course of construction shows how the mitigation planner prevents the unbalanced spending through timely placed mitigations leading to evenly spread out additional costs.

Improving probability of timely completion for a single condominium from 3.74% to at least 50.31% while only spending an additional 2.18% of construction cost of a single condominium, and increasing the probability of timely completion for the entire Olympic village from 0.11% to at least 51.11% while spending less than 1% of total construction cost of the entire village, are both promising results that using the Mitigation Planner does not only spread out spending across the entire life cycle of the project but also drastically improves the probability of timely completion.

Ultimately many things went wrong in the organization of the Rio Olympics, some of which cannot be controlled such as political instability, but construction progress and activity status can be monitored and better planned and scheduled. This is where the recommendation to the IOC goes out to use the Mitigation Planner. As stated earlier in the research, if the IOC enforces such a tool like the Mitigation Planner on the host countries to ensure timely completion and help the host avoid the unbalanced spending caused by the unplanned additional costs due to unforeseen delays, this would allow entrusting the Olympic games to less developed countries, with less skilled individuals such as Brazil.

Taking the Rio Olympics and the Olympic village as an example, if each condominium had its own manager keeping an eye over the construction while using the Mitigation Planner, the construction of each condominium would have cost on average only an additional 2% of total construction of a single condominium compared to the 4% assigned in reality, while also delivering the condominium on time. Additionally having a manager overlooking the big picture, and based on the PDM results, this manager could place mitigations to make sure the entire project finishes on time, and hold meetings with the respective condominium managers to keep informed about the status of each single condominium. Communication is key;

if everyone knows what is going on it will be easier to identify the problem and the corresponding mitigation to deal with this problem.

Blaming only the organizers of the Rio Olympics for the delays and problems faced would be a mistake, as the IOC also has some blame to carry. As was established in chapter 2, Rio was one of 5 shortlisted countries in 2008 chosen to host the games. While having the lowest weighted average score, Rio still managed to win thanks to the high government support score, but also had the lowest safety and security scores due to the city's violence. As corruption is nothing new in a country like Brazil, it was a little bit shocking that after a conversation with Mickey Huibregtsen, chairman of the Dutch Olympic Committee (NOC*NSF) from 1990 to 1998, it was established that even "*the IOC is a totally corrupt system*". When asking Mr. Huibregsten about why he thinks Rio still got chosen despite the lower scored he gave two possible reasons:

"

1. *The honest and honorable explanations: From a strategic point of view, one felt South America should organize the games.*
2. *Power influence and granting "favors"*

It's hard to tell which of the two explanations it is, but it would be interesting to get the individual votes, but obviously the IOC is one of the least democratic institutions in the world, in a sense that they are not elected, they are not subject to any democratic verification, ***there's no transparency whatsoever****."*

The point of presenting these short phrases of the conservation with Mr. Huibregsten is to show how vital transparency is or at least should be. The Mitigation Planner cannot provide transparency in politics, but it can bring transparency in the construction domain. This research is not meant to tell the IOC what to do with these corruption problems, but rather to provide a helping tool that can make at least the construction part for the host country of the games more transparent in the sense that it can throw light on what activities need more work or additional mitigations, and make it clear, at any point in the project, what the status of progress is and what still needs to be done to ensure timely project completion.

Finally I end this Thesis research with two recommendations:

First recommendation goes out to the IOC, and anyone else having the task of planning and managing a construction mega-project such as the Olympic games. Using the mitigation planner in early phases of the project can help provide a better overview of probability of timely completion of the project, in addition to identifying the need for mitigations early enough for the activities that are presented by the mitigation planner to be critical. This way, when the time comes and problems occur which would normally be cause for a delay, the mitigation to deal with this problem is ready to amend that problem. Even if no mitigations are used, the mitigation planner can provide an indication of whether or not the project will finish on time given the project duration, and whether changes need to be made. For this to be possible and as was stated earlier in the research all the required information is needed early enough to be able to react swiftly.

The second recommendation is for future studies and it is to further improve on the mitigation planner, making it more realistic in terms of actual reaction time and how engineers deal with problems faced rather than ignoring the fact that engineers and managers do everything possible to finish the project on time. The mitigation planner already does that, but there is always room for improvement, such as removing the awkward break in the graph representing the probability of timely completion, making it a smooth graph, and making sure all mitigation effects are taken into account even the infeasible ones, as managers will still use “Mitigation X” if it helps complete the project faster even if it means missing the deadline.

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