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Optimization of Flowline Scheduling vs. Balanced Resources and Task Continuity

Natalia Rodriguez Martinez

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Supervisor: Olav Torp, BAT

Co-supervisor: John Skaar, Skanska

Norwegian University of Science and Technology
Department of Civil and Transport Engineering



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Name: Natalia Rodríguez Martínez				
Professor in charge/supervisor: Olav Torp				
Other external professional contacts/supervisors: John Skaar (Skanska Norge AS)				

<p>Abstract:</p> <p>This master thesis is a study of the location-based management systems (LBMS) in construction projects. First, a review of the history of both the traditional (CPM, PERT) and the new methods (LBMS) set the basis of understanding for the need of changing the approach in planning. This change claims for an evolution from the activity-based planning to the location-based as a response to the change this production type has suffered, especially with the introduction of new philosophies as lean construction. As the scope of the thesis is limited, the focus will be mainly in the consequences towards task continuity and resource balance.</p> <p>With the development of LBMS have appeared also technical tools to support its implementation. Among these tools is VICO Office, a software developed to implement this new planning perspective. A case study is used in this thesis to exemplify the use of VICO Office and to see how the transition and optimization of a traditionally planned construction project can be undertaken. The case study is part of Skanska Norge AS portfolio in Oslo (Schweigårdsgate 21-23).</p>
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Keywords:

1. Location-Based Management
2. VICO Office
3. Lean Construction
4. Task Continuity
5. Resource Balance

PREFACE

This master thesis represents the final project developed under the MSc in Project Management and it has been written under the supervision of the *Bygg, Anlegg og Transport* department at NTNU. Initially thought as a continuation of the specialization project written in the previous semester, it goes through more specific tools and methodologies in relation with the lean principles within the construction industry context.

As already seen in the specialization project, the construction industry is evolving from the traditional planning perspectives to new approaches as the one offered by lean construction. This evolution is the answer to a need of adaptation to the new market requirements, to be efficient and sustainable, or in other words keep the competitive level. Together with the lean principles, there have arisen new planning methods which focus in these new needs. The core of this thesis focus in one of these new theories: *Location-Based Management Systems (LBMS)*.

The idea for choosing this topic comes from the realization of the existence of a complete innovative approach in the planning construction practices, with a high potential to improve the actual methods deployed. With the support of the computational solutions recently introduced commercially, the chances to improve construction scheduling as we know it nowadays are enormous. In particular, the use of solutions as VICO Office software could represent the future of planning and controlling construction projects.

The objective here is to set the basis where this new approach is established and evaluate the further possibilities of both the theoretical approach and its implementation through real tools as VICO. To do so a set of literature about the topic will be reviewed and a real project will studied under this perspective. Since the use of software in planning is a current practice in the companies, VICO Office will be implemented in the case study to get a more realistic perception of its potential use with LBMS.

Going through the comparison of the traditional and the new planning methods has been an excellent learning process. Besides the merely theoretical background acquired, also the use of the software and the analysis of its use in a real scenario has provided a valuable experience towards future professional prospects.

I would like to thank those who helped both with the creation of the idea itself of this master thesis and its development. It has been a great support in terms of supervision and guidance, but also for the possibility of joining proper training in the tools used and to get a closer glance to the construction industry in Norway. I would like to thank especially Olav Torp (supervisor at NTNU), John Skaar (supervisor at Skanska) and Lars Aasen (project manager of Schweigårdsgate 21-23).

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LIST OF ACRONYMS

BoQ – Bill of Quantities
CPM – Critical Path Method
GA – Genetic Algorithm
IGLC – International Group of Lean Construction
LBM – Location-Based Management
LBMS – Location-Based Management System
LBS – Location Breakdown Structure
LCI – Lean Construction Institute
NTNU – Norwegian University of Science and Technology
PERT – Program Evaluation and Review Technique
RSM – Repetitive Schedule Methods
TPS – Toyota Production System
UiA – University of Agder
WBS – Work Breakdown Structure

SUMMARY

This master thesis provides a study of the location-based management systems (LBMS) introducing its main elements and methods, and understanding its roots in the traditional and lean planning philosophies. The report comprises two parts: a theoretical study of the LBMS and a practical approach through a case study. Thus, the aim is to implement in a real scenario the methods and practices studied in theory, to assess the improvement they represent in comparison with the traditional planning schemas. Since the scope of this thesis is limited, the study focuses mainly in the implication of the scheduling optimization in the task continuity and the resources usage.

The theoretical study starts with an analysis of the history of planning in construction with especial emphasis in the evolution from the activity-based methods to the location-based ones in which LBMS is found. Since the logical network methods as CPM or PERT are still the mainstream in planning methodologies, their flaws are pointed out to evaluate the need to change towards new planning perspectives. In addition, the main traditional methods for resource allocation and leveling are considered.

On continuation, the development of LBMS and its history is studied in relation with the traditional planning methods and with lean construction. The common concepts and principles between those approaches are identified and the main elements of LBMS defined.

Once the background of LBMS is established, flowline schedules are studied as its main planning tool. Here there is also a comparison with the traditional Gantt charts, which are a common diagram used for scheduling nowadays. The study considers the scheduling process itself but also the prerequisites to undertake it, as for example, the availability of the project geometry (3D model) to set the basis for the project locations.

The features of a flowline schedule allows an optimization process from a graphical way. Considering the activities to be performed in each location and desired working rates, it is possible to adjust the lines representing each task to encompass the same rhythm. This can be done in the graphic itself aligning the lines as desired. Thus, the workflow

can be established as required by the project constraints. This representation allows the user to identify deviations of the plan, make forecasts and follow up the project progress easier than with other kind of charts.

As the theoretical progress evolves, there is also a need for software tools. VICO Office is a software which development started in Finland closely related with the development of the LBMS theory itself. A review of its features and modules is done in this thesis focusing in the workflow followed in the planning process, integrating the 3D project model with the costs (4D) and time (5D).

The use of a case study establishes a real basis to deploy the theory and tools previously studied. Hence, an assessment of the validity of these practices regarding the traditional ones used can be done. The focus is in the benefits LBMS represent when it comes to the establishment of the project flows, especially the tasks along the project and the resources performing those tasks.

After exposing the theoretical and practical aspects with the literature study and the case study, these set the basis for the debate of some specific aspects. Here there is a comparison of the use of flowline and Gantt charts for scheduling. The use of the LBMS and the resource methods in the case study is argued considering other aspects of the project as the involvement of the subcontractors. The use of VICO based in BIM is also questioned, in relation with the use of highly detailed models as basis for planning and the current practices where changes in the project solution appear until late phases of construction. Finally, a closer look to the previous and post optimal situations of the case study is taken using the outcomes of the software used.

To finish, a set of conclusions based in the case study outcomes, the points discussed and the theoretical framework established are inferred. Additionally, given the limited scope of this project, there is room to suggest the possibilities for further work and the directions a subsequent study could take.

1. INTRODUCTION

The construction business is becoming more demanding gradually. New technical approaches and methods make competition within the companies in the sector a great challenge. To adapt to such market and keep progressing towards a more efficient use of the time, resources and costs while increasing the value created with the projects, it is needed to implement new management solutions.

The introduction of the lean principles in construction with a focus in elimination of waste in the workflow towards a pursued perfection of the production, represents a breakthrough in this industry. After its deployment, other theories based in the same criteria are arising and acquiring more popularity. This thesis focuses in the *Location-Based Management Systems (LBMS)*. This innovative tool provides a new perspective that takes the project physical features with its single locations in particular, as unit of analysis when planning. This is a complete shift from the tools that have been and are still used in construction planning.

The main objective of this thesis is based in a learning purpose and will be defined in the research questions. Hence, the aim is to understand how and why LBMS have been developed, in answer to which current need this tool arises. In addition, the different methods and practices in relation to LBMS will be examined and a commercial software currently in use in the market will be implemented in a case study. In order to see how beneficial the use of this new approach is compared with the traditional planning methods, in particular with the use of logical network methods and Gantt charts, the case study will be set in a real project scenario where the optimization of a flowline schedule (LBMS schedule) will be undertaken.

A project is composed not just by many tasks, but also by many aspects and dimensions. This master thesis has a defined scope given especially the time limitation. Therefore, only some aspects related to project scheduling will be considered. Thus, the focus of evaluation will be the effect of the optimization of flowline scheduling in task continuity and resource loading.

2. METHODOLOGY

The object of this master thesis is to evaluate the practical application of location-based management as a planning tool, and find out how an optimal implementation of the method and theoretical principles affect the project planning process. There will be two main points under consideration for such evaluation: task continuity related to the expected and the actual workflow, and resource leveling to reach the targeted production rates.

2.1 RESEARCH QUESTIONS

To structure the objectives that this master thesis seeks to reach in terms of knowledge, a set of research questions have been established. The sequence of the questions comes along with the two phases described of theoretical basis establishment and evaluation of the theory implementation.

Theoretical frame definition:

- What is understood by Location-Based Management System (LBMS)?
- How are LBMS and lean construction related? (with special focus in the concepts of flow and pursuing of perfection)
- What is flowline planning?
 - What is its supporting theory?
 - What are its elements?
- How can flowline planning be optimized?

Implementation evaluation:

- What are the effects of this optimization in the project resources and task continuity along the project?

2.2 THEORETICAL FRAMEWORK

Given the research questions defined in the previous point, it is important to set an appropriate line of research according with the master thesis scope, the time frame available and quality constraints existent. Firstly, it is needed to establish the approach from which the study will be undertaken. This will subsequently set the way in which the data will be gathered and analyzed, and the kind of conclusions that the research questions are aimed for.

2.2.1 Qualitative vs. Quantitative research perspectives

An initial step to define the research study features is to establish the perspective relative to the research methods to be used according to the desired approach to the topics under consideration. Thus, it is required to choose whether the study will be undertaken from a qualitative (descriptive research), quantitative (explanatory research establishing causal relationships between variables) or a mixture of both perspectives. The next table compare the main characteristics of the two opposite methods.

QUALITATIVE	QUANTITATIVE
Understand and interpret the social interactions embed in a phenomenon or event	Test of hypothesis, cause/effect reasoning, make predictions
Small group of elements under study not randomly selected	Large and randomly chosen group under study
Study of the whole event and not just single variables	Study of specific variables
Data: impressions, images, objects, etc.	Data: numbers, statistic metrics
Data gathering: interviews, questionnaires, observation, field notes, reflections, etc.	Data gathering: measurements using structured and validated data collection methods
Not generalizable findings	Generalizable findings
Focus in quality, behavior and complexity	Focus in quantity, scales and trends
Answer the questions 'why' and 'how'	Answer the questions 'what' and 'how much'

Table 1 - Qualitative vs. Quantitative research methods characteristics (Thomas, 2003)
(Saunders et al., 2011)

2.2.2 Research study design

When it comes to the study design, this paper will focus in the qualitative approach but it will also be supported by quantitative analysis (use of VICO with real project data), so it could be said that it will be a blend of descriptive and explanatory research methods. The first one will allow portraying a profile of the event under study, which in this case will be the project management under the location-based principles. This event will be exemplified with the help of a case study. The case will provide the actual scenario of a real project to be analyzed. In addition, a commercial software tool will be used to undertake the optimization itself of a part of the case under study, and evaluate the ideal theoretical solution with the current one, focusing in some of the parameters involved. Therefore, it will be possible to establish the causal relationships existent between the variables considered in the process optimization (Saunders et al., 2011).

There are two main phases in this study. The first one will be focused in the understanding of the elements, theory, development and methodology under flowline scheduling. As a continuation of the specialization project that treated about lean construction, the common principles between lean philosophy and location-based management in construction will be analyzed. This will be done through a literature study that will settle the background to undertake the next phase. A second phase will be a case study that will be the ground to use the theoretical basis established together with actual tools such as VICO Office. An evaluation of the implementation of the theory in a real scenario will help to prove its actual use in the construction industry.

There are many possible ways of gathering the necessary information to develop the two study phases previously stated. Both phases of the project need a theoretical basis which will be set through a literature study. Thus, the background, history and elements of the topic under consideration will be established, and a proper understanding will be reached. For the second part, it is important to set clearly the context of the case study, the company, tools and methodologies used to get a whole picture of the variables under consideration and comprehend what are their role in the project and its management optimization. To gather all the necessary information about the case, a close collaboration with Skanska Norge has been established, especially with the help of

the supervisor John Skaar and the project manager Lars Aasen. These two persons have been a great source of information about the theory underneath the project planning implemented in the case study, the tools used and a key contact to reach the subcontractors. The methods used to collect information have been structured interviews followed by dialogue, questionnaires with multiple answer questions and open questions, observation and secondary data in form of project reports, plans and other relevant documentation.

2.3 LITERATURE SEARCH

Following the experience gathered in previous projects and reports, a systematic approach will be followed to undertake the literature search. Using an already established procedure will help to reduce the time consumed in this task and to reduce its complexity in terms of gathering and sorting the information. As a result, the evaluation of such information will be easier, faster, and more efficient. Keeping track of the references and coming back to certain sources of information will be also a simplified process and will help avoiding information overlapping and time wasting in general. Moreover, it is needed to keep a realistic approach when selecting the sources and analyzing the references given the limited time to undertake this task.

The methodology design is partly the result of an assignment given by another course (TBA4151-Construction Engineering, Advanced course). The assignment itself had as objective to carry out the literature research and develop a suitable approach to do so for a topic chosen by the student, which in this case was lean construction. The result was a systematic approach when it comes to choose the sources and references, which allows the follow up of the resources used and the status of the research itself. The advantage of such a schema is to keep an order in the structure to be able to continue further the searching with the maximum efficiency of the sources and time used. The process contains three main points, which have been undertaken using a set of tools to facilitate the information gathering and managing processes:

- Choosing the information sources.
- Defining the scope of the search.
- Selection process: screening.

2.3.1 Choosing the information sources

As having the information under a same format facilitates its management, it has been prioritized the use of online tools and searching engines. Thus, it has been possible to process and store the information with the support of other tools such as EndNoteX6 or Excel spreadsheet. Even though it has been possible to get an online version of all the

references, some of them were only found in traditional formats as books. Therefore, a combination of the traditional with the modern information formats has been considered.

These sources can be classified in four branches:

- Online libraries
- Databases
- Internet websites
- Conference and journal websites

2.3.1.1 Online libraries:

- BIBSYS (NTNU and other universities/colleges in Norway)
- ASCE Library (American Society of Civil Engineering)

NTNU and other high education institutions offer an online search engine through their libraries, which enables the search for books, master thesis and other publications. Particularly at NTNU, it is possible to find not only hard copies of the books needed but also in some cases digital copies such as e-books, which facilitates the management of the information and its future use in this project. In addition, other online libraries have been a source of useful references such as 'ASCE Library'.

A book in particular (*Location-Based Management for Construction*, Kenley & Seppänen, 2009a) represents one of the greatest sources of information related to LBMS in this thesis. This is due to the large theoretical scope it covers in the topic, being the most complete reference used for this report. Moreover, the existent literature directly related to LBMS is limited, so the amount of authors and studies is reduced compared with other topics as lean construction, for example.

2.3.1.2 Databases:

- Scopus
- Science Direct
- Knovel

Since there is an innumerable amount of databases and it would take too much time to review all of them, three main databases have been chosen: Scopus, Science Direct and Knovel. The reason to choose these ones is the previous experience with them in other projects together with EndNote, making the reference management a straight process.

2.3.1.3 Internet websites:

- Google scholar
- Companies: Skanska, VICO Software
- Organizations: Lean Construction Institute (LCI), International Group of Lean Construction (IGLC), etc.

It is easy to find sources of information on the internet but it is important to be aware of their validity. Only reliable sources must be used and even though, the information found will have to test its *Reliability-Objectivity-Accuracy-Relevance criteria* (NTNU, 2013). Thus, only a few sources were chosen.

2.3.1.4 Conference and journal websites:

The search on the internet had as a result the finding of many interesting research publications about the topics under consideration in this master thesis. These publications are related in some occasions to professional organizations as ASCE or institutions as NTNU or UiA.

Even though some of the publications come from non-English speakers authors, it was not an issue to go through and understand its content.

2.3.2 Defining the scope of the search

To keep the search within the topic under interest, given the extent of the related literature, a set of keywords have been used. The objective is to keep the focus in the main points under consideration: location-based management systems, task continuity and resource balance. Moreover, of course, set the context of these subtopics within

the construction industry to analyze the common practices and implications in this business sector.

Moreover, the implementation of Boolean operators as AND/OR allowed the combination of the keywords among themselves and together with the words 'construction' and 'building' to narrow the search.

The keywords chosen were selected in order to sort the literature found in the next groups. These groups and their corresponding searching keywords are:

GROUP	KEYWORDS
Location-based management systems	Location-based management/planning/scheduling
	Flowline planning/scheduling
	Soneplanlegging
	Skråstreksplanlegging
Logical network methods	Logical network scheduling
	CPM
	PERT
Resources planning	Resource planning/balance/leveling/loading
Task continuity	Task continuity
	Activity continuity
	Workflow

Table 2 - Classification of the keyword groups

2.3.3 Selection process

The selection process has two different stages: a first approach or review of the references, and a screening process to select the references to be used. The intention when structuring the process in this way is the possibility for its further development by extending the search if necessary. As the references have been collected and stored as previously mentioned, the methodology allows keeping track of the references avoiding repetition of the same titles.

- First approach/review: reading the abstracts and summaries of the articles enables to get a quick overview of the information contained without spending too much time. When the source is very extensive, it is recommendable to

analyze the table of contents or other indexes that can give an idea of the main topics treated.

- Screening process: in this case, there have been two phases in order to narrow the amount of references as required for the report study. The aim of the screening is to test four criteria to be compliant with: **reliability, objectivity, accuracy and relevance**. In the first part of the screening stage, reliability and relevance were the main targets to accomplish. The second stage of the screening is focused in the objectivity and accuracy of the content of those references selected as favorites in the previous step.

Reliability has been tested by checking the sources of the papers, giving priority to the academic and conference publications that have already been published officially by reputable institutions or organizations.

In order to test the relevance, it is essential to have set the goals about the topic under study and delimit its scope.

Objectivity and accuracy need a more in depth analysis, which needs the full review of the paper. In terms of objectivity, a comparison of the different references between them can be made to find the different perspectives if existent, and any trace of biased information.

2.3.3.1 Tools

There have been a set of complementary tools used to sort the information and keep track of the status of the search (*See Appendix B*):

- Excel spreadsheet: to keep track of the status of the search by checking the keywords and combination of words used in the different databases or websites.
- EndNote X6: to sort the references in the previously mentioned groups. It also allowed storing the main info about each reference like abstracts, authors, sources or the attached pdf documents. An additional advantage of using this program is the use of the citations in the text and the list of references. This is because it allows formatting the reference as desired and being included easily in the text written.

2.4 VICO COURSE

Since part of the master thesis is strongly based in the implementation of the location-based management principles, the best approach is to use a real basis for its analysis. This means to study a real project as if it was managed in a real work environment. To do so, it is needed to learn to use the tools related to the common practices in LBM. VICO Office is indeed a gradually further widespread computational solution for construction management, and therefore it is worth to be used in this master thesis.

Since its relatively recent implementation in Skanska, the company has started to provide training to the employees, so they can undertake an efficient use of the software. As part of the facilities that Skanska offered me as student, was the opportunity of joining a two days training course. The course itself took place in February in the VICO offices in Solna, Sweden. The main focus of the course was learning how to use VICO Control 2009, aimed for scheduling, tracking and controlling of construction projects. This software allows the user to:

- Create location- and quantity-based schedules
- Optimization of schedules
- Monitor and forecast the project process
- Run 5D simulations with the integration of the project 3D (geometry and quantities) and 4D (cost) data

Once understood both the theory underlying the LBM and the software related, it is possible to use it together in the case study. Thus, it will be possible to undertake a realistic analysis of the case and infer critical conclusions about it.

2.5 CASE STUDY

A case study is a qualitative research tool based in an empirical perspective of an event or phenomenon studied in its real context. To undertake this kind of study it is necessary to approach a data gathering process from multiple sources to be able to represent the event in the most reliable way (Saunders et al., 2011).

There are other kind of studies related to qualitative methods as ethnographic or phenomenological studies, which are more focused in the social variables and interaction of the different behaviors, but due to the technical nature of the topic under consideration, here it was chosen to keep in mind an engineering point of view. Thus, a case study as a way to portrait the project management under location-based principles as a phenomenon is more suitable as a research method.

The case study helps supporting the theory gathered during the literature study, exemplifying the location-based management principles and giving an answer to the application related research topics (see 2.1 *Research questions*) mainly from a qualitative perspective.

If the focus would have been a quantitative analysis, another possible perspective could have been to use a statistical study, but due to the desired approach and the reasons given on continuation it was dismissed.

It is certain that a case study does not provide a general representation of a generic process as a statistical study could do. On the contrary, it does represent a single event in a more realistic way than approaching it in a merely quantitative way through statistic metrics. It exemplifies the real behavior of the process in its actual context giving a detailed description of the elements, environment and sub processes involved. Moreover, it is a more flexible kind of study which can undercover unexpected features of the event under consideration. It is a multidimensional study, which focuses in '*why and how*' is happening. Meanwhile, a statistical approach only focuses in one dimension at the time quantifying '*what and how much*' for a determined parameter.

As stated, a case study has been chosen and a plan was set for the data gathering and its subsequent use. The project under study is part of the Skanska portfolio in Oslo:

Schweigårdsgate 21-23 which will be the new offices for the companies NSB and Gjensidige.

2.5.1 Data gathering

There have been several sources of data for the case study as the analysis of the project documentation available: reports, plans, MS Project files (Gantt diagrams, etc.)

- General information about the project and its context
- Required activities to be performed in the project, and which subcontractors will undertake those.
- Resource loading.

Site observations:

- 'Zoning' (possibilities) for the location breakdown structure (LBS).

Interviews (Project manager) and questionnaires (subcontractors involved):

- Flow/work continuity. How is the real perception of this concept in the project compared with their theoretical knowledge.
- Involvement of the different parts in the resource planning.
- How tasks are actually performed in comparison with the plan.

2.5.2 Use of data

Once the data is gathered, it will be analyzed taking into account the theoretical basis acquired throughout the literature study. After the data analysis, the next points will be considered:

- Evaluation of the project planning with VICO Office. Due to the thesis scope, it will be undertaken just in a part of the project containing, for instance, a determined set of activities. This plan will be compared with the current project plan with the site observations about the possible zonification choices and the project documentation data as information basis.

- The information gathered with the interviews and questionnaires will be used to discuss the implication of the project leader and subcontractors in the planning and their actual performance related to the project workflow and task continuity.
- Concerning the resource planning, an assessment of the actual methods used compared with the possibilities of LBMS will be done. For this, both interview, questionnaires and project data will be used.

3. LITERATURE REVIEW

3.1 HISTORY OF SCHEDULING AND PLANNING IN CONSTRUCTION

Scheduling and planning in construction has nowadays a vital role in project management, which has been developed throughout its history especially during the 20th century. After a period of rapid changes in the 19th century and introduction of new industrialized techniques of construction, new equipment and new materials, the focus in the scheduling and planning of projects raised as a support to this technological development.

The evolution of construction has been linked to the history of other kinds of production: from its beginning as a mainly craft production of hand made and unique products; to the mass production where repetition and standardization were sought; and the industrialized production where prefabrication of the product parts was essential; to finally get to the application of the lean philosophy. Despite the common historical roots of construction and other industrial production types, construction has been always a singular production system and so its progression.

This evolution of industrialized construction between the 50's and 70's was focused in prefabrication of components off-site, which failed to satisfy the increasingly fragmented and diversified demand. At the same time had its origin the so-called '*lean thinking*', which started in the car industry with the Toyota Production System (TPS), developed in Japan. This new production philosophy settled the roots of a new way of construction called '*lean construction*', which could meet the needs that the mass or industrialized construction could not. The basic concept underlying this new kind of construction was the identification of waste in the construction workflow to keep it as smooth and stable as possible with the aim of following an iterative process that seeks to reach perfection of work and management. Even though the concepts of workflow and variation reduction might seem a breakthrough reached by lean construction, they had already been introduced in the mass construction (Sacks & Partouche, 2009).

System features	CRAFT CONSTRUCTION	INDUSTRIALIZED CONSTRUCTION	MASS CONSTRUCTION	LEAN CONSTRUCTION
Nature of the building products	Unique components Unique spaces	Uniform components	Uniform components and uniform repeated spaces	Customized spaces
Labor	High-skilled trades	Low-skilled but highly specialized	Specialized trades with narrow focus	Multi-skilled teams
Flow system	No consideration of flow	Push flow-discontinuous flow	Continuous flow (stable due to uniform products)	Pull flow
Batch size	Small batches	Large batches	Large batches	Small batches
Inventories	Small inventories	Large inventories of components	Large inventories of components off-site Large inventories of spaces	Small inventories
Logistics	No logistics system	Off-site materials logistics system	On-site materials logistics system	On-site and off-site logistics system for all resources

Table 3 - Key characteristics of four different construction systems (Partouche & Sacks, 2009)

Through history, many different scheduling methods have been developed with different focuses and characteristics. A categorization in two main typologies can be set in order to follow the line of study this report will take. These two groups are activity-based and location-based methods (Kenley & Seppänen, 2009b).

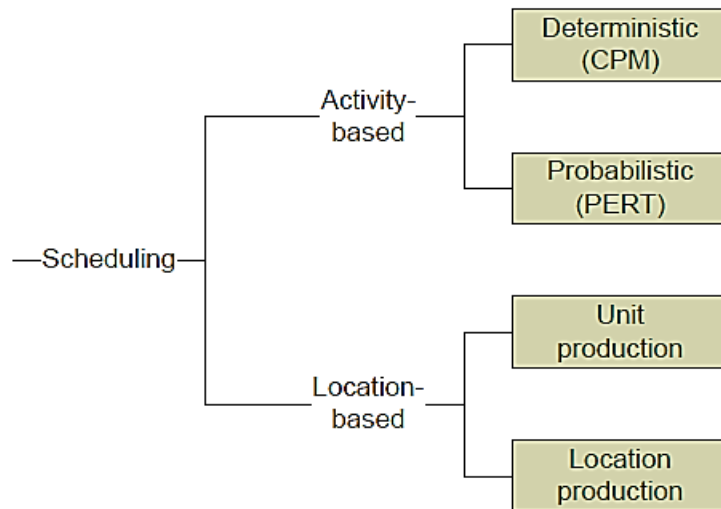


Figure 1 - Typology for construction project scheduling methods (Kenley & Seppänen, 2009b)

Activity-based methods

These have been the predominant scheduling practices concerning Project management in construction from the 50's, when they were first developed. These methodologies treat the project as a set of discrete activities related through logical relations. In this way, projects can be modeled according to work packages and the relations between them. The activities are the units of analysis containing the data needed to describe the tasks to be performed in the project. Activities can be treated as deterministic units included in a logical network. This is known as the *Critical Path Method (CPM)* and seeks for the calculation of the minimum duration to complete the network of activities. If, on the other hand, the activities are treated from a probabilistic perspective we would be using a *Program Evaluation and Review Technique (PERT methodology)*. In this case, the aim is to assess the likelihood and risk of the activities to be completed on a determined date. With the help of simulation methods as Monte Carlo, all the activities of the network can be integrated and the total duration of the project estimated (Kenley & Seppänen, 2009b).

Location-based methods

These scheduling practices are based in following up the continuity of resources working on tasks. The method was initially performed as a graphical tool originally based in the technique developed by Karol Adamiecki in the early 20th century. Adamiecki is considered as the father of the location-based scheduling methods. Contemporary with the widely known Gantt and Taylor, he would focused his research among other things in the efficiency of production and the development of *three laws of economy* (Kenley & Seppänen, 2009b):

- Law of work division
- Law of concentration
- Law of harmony in management

These laws have especial significance for the development of the *Location-Based Management Systems (LBMS)*.

Adamiecki developed his own schedule tool called *harmonogram*, which in contrast with the Gantt diagrams included the locations as key element of scheduling.

As example of the application of Adamiecki's concepts, the Empire State Building is one of the first projects that took the project locations as main unit of analysis. Built by the Starret Brothers, this project put especial emphasize in its coordination and management. Thus, the different flows existent (information, work, materials, people, equipment) together with the consideration of the project locations availability and external project conditions were the main points considered. The result was a historical record for its construction rate with around 380 m² built per day of construction (CTBUH, 2013), completion of 102 levels in 18 months with high safety records for its date, and under the initial estimated budget (Sacks & Partouche, 2009).

Location-based scheduling methods consider repetitive activities for their basis and are included in the group of methods known as *Repetitive Scheduling Methods (RPM)* (Harris & Ioannou, 1998). The main concern of these methods is the movement of resources through locations or places, so there is not really a need for repetition. Here tasks are considered as a group of activities that happen over different locations subsequently.

Thus, a project can be modeled as a group of work packages or activities included in the different tasks, representing the aggregated activities happening in multiple locations, which are linked through a logical relationship network.

Simultaneously, it is possible to subdivide these methods according to their focus in unit of production or location of production. Therefore, *Line of Balance* is focused in the completion of repetitive units meanwhile *Flowline* is focused on the completion of variable physical locations (Kenley & Seppänen, 2009a).

- *Line of Balance*: this scheduling method combines mathematical and graphical techniques, focused on the production units per time period. It requires equally defined units of production.

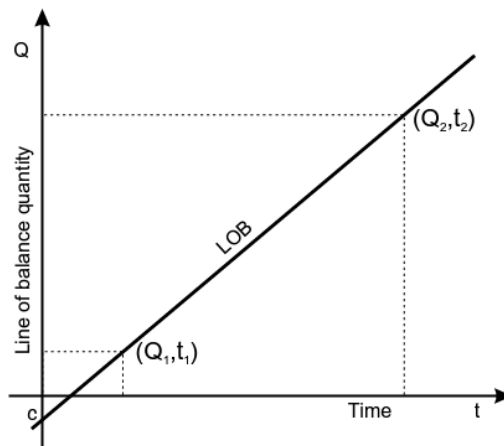


Figure 2 - Line of Balance linear relationship (Kenley & Seppänen, 2009a)

- *Flowline*: this method focuses in the workflow within locations and its rate of completion. On the contrary as line of balance, it does not require location units to be equal, so the different locations may vary in quantities or tasks to be performed in (Kenley & Seppänen, 2009a).

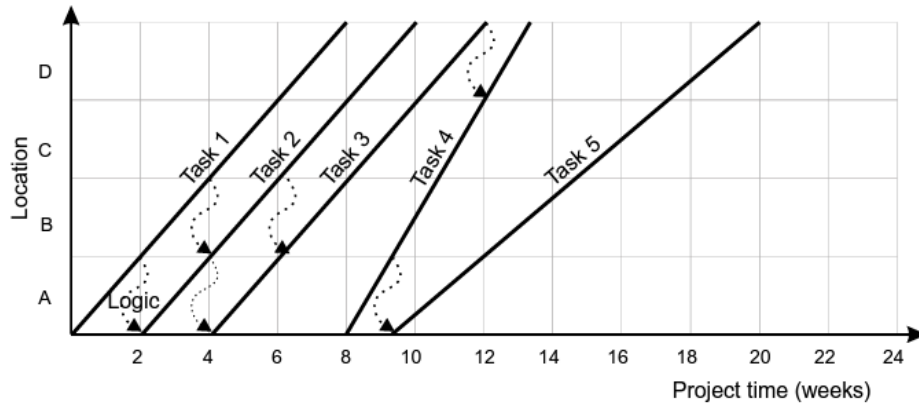


Figure 3 - Flowline schedule for tasks 1-5 in locations A-D (Kenley & Seppänen, 2009a)

This master thesis is oriented to the study of the location-based scheduling methods, in particular of those based in location production units (Flowline).

3.1.1 Logical network methods: CPM and PERT

Historically, CPM has been the most widely used scheduling method in construction. However, this does not mean that is the most suitable one, as researchers have noticed lately. In the 70's, a research developed by the Technion-Israel Institute of Technology (Haifa, Israel) with Shlomo Peer as head of the department of Construction Management and Economics, started to identify the weaknesses of CPM when applied to construction projects. In 1974 Peer found that the use of resources in construction was not well represented by CPM (Peer, 1974). In part, this is because of the unrealistic assumption of unlimited resources and independency of the activities in the logical network, but also for the neglect of the continuity and balance of the workflow into an integrated production system (Kenley & Seppänen, 2009a).

Even though CPM does not fulfill the needs of the construction production system as location-based methods do, the latter ones use logic relationships to define the activities sequence, which relies in part in the logical relations available in the CPM logical network. Therefore, to understand completely the location-based methodologies it is needed to analyze the CPM first.

The CPM was developed in the 50's. The company E. I. du Pont de Nemours (DuPont) started the research about the topic in 1956, and this work would be followed by the researchers Kelley and Walker who will coin the term critical path method referring to the main role of the project critical activities in the method. They would also define its project structure as a logical network with four levels of complexity: deterministic, probabilistic, general activity networks and critical chain method (Kelley & Walker, 1959).

This method uses network diagrams to visualize the relations between activities. Each activity in the network is described by its duration, and the links between the activities in the network are represented by arrows. The activities can be moved in time along the network as long as the relationships with the other activities remain. In the simplest case, the duration of the activities is assumed to be deterministic, and typically equal to the most likely value for its duration. Running the network from the project beginning to its end enables to find the different paths that will determine the different possible durations these ones have. The longest path is called *critical path* and determines the shortest total length of the project (Pinto, 2012). Since the approach of this method is deterministic, it is not possible to handle the uncertainty of each activity. This can be done however, if the approach is done under a probabilistic perspective through the *Program Evaluation and Review Technique (PERT)* (Vatn, 2008).

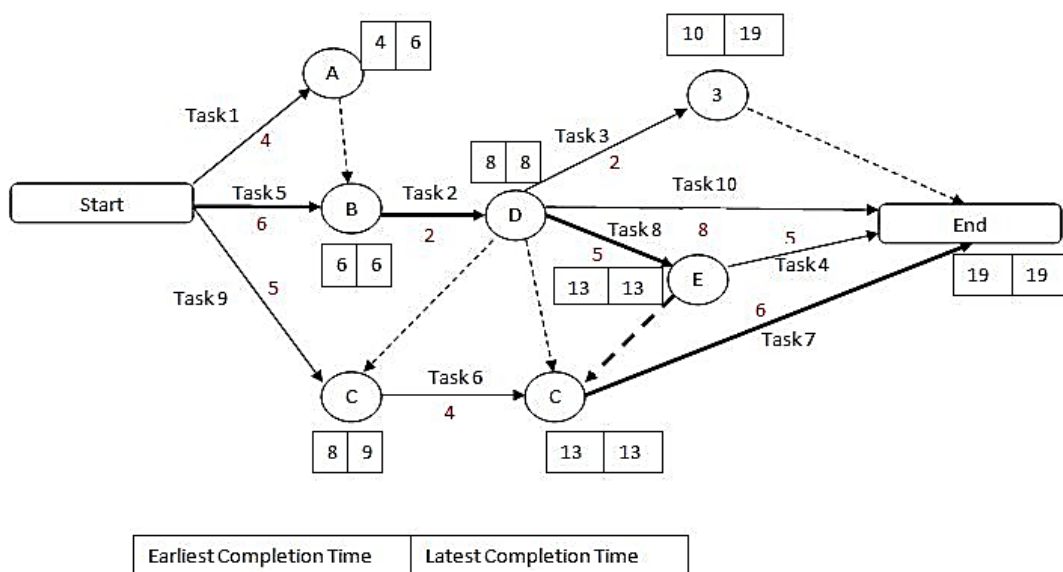


Figure 4 - Example of a CPM network (Coder, 2013)

The main focus when using logical network methods for scheduling is the optimization of the project duration rather than focus in the resources constraints to keep adequate and smooth flows of work, crews, materials, information, etc. On the contrary, LBMS has a different perspective focusing primarily in the workflow and labor productivity of the project.

3.1.2 Why logical network methods are not suitable for lean construction

Even though the use of logical network methods has been accepted and widely used in many different kind of projects there are some controversies in their use (Pinto, 2012):

- In large and complex projects the networks become very large and difficult to understand, so they lose their meaning as a quick visualization tool to obtain the 'big picture' of the project.
- Improper reasoning during the construction of the networks can lead to incorrect representations or excessive simplification of the project activities.
- Logical network scheduling is not a universal tool and therefore is not valid for all kinds of projects, as for the case of construction projects.
- When there is a high number of contractors, it may be challenging to represent in a unique network all the schedules under consideration. Access to all the schedules and information is crucial to integrate them all. Here communication and transparency are the key issue.
- In the case of PERT, the estimations may be biased leading in some cases to overly optimistic durations. The results can be inaccurate and not representative project schedules.

Despite of the predominant use that CPM has had in the building industry, it has been proved as not the optimal method when it comes to the implementation under the lean construction practices. This new construction philosophy is especially suitable for projects containing repetitive activities, which require a continuous and interrupted use of the resources in the activities sequence. CPM has been criticized for its limited resource operability given its inability to manage and monitor the limitations especially

in construction projects. Given a high level of repetition, it often happens to be different production rates along the project time leading to inefficient resource usage. The CPM only considers technical constraints to set the precedence relationships among the activities and the resource availability. Hence, other kind of scheduling methods called *Repetitive Scheduling Methods (RSM)* are more suitable. Among these methods it is located the *Location-Based Management (LBM) scheduling*, which in contrast with CPM is not activity-based but location-based and it focuses in the work continuity along the different project locations (Andersson & Christensen, 2007) (Harris & Ioannou, 1998).

The definition of construction seen as a production type could be stated as:

‘The production of a complex one-of-a-kind product undertaken mainly at the delivery point by a series of repeating but variable activities in multiple locations within a multi-skilled ad-hoc team’ (Kenley, 2005).

According to this definition, it is clear that a location-based scheduling approach is more suitable than an activity-based one. It is when it comes to repetition of activities and reduced variability in the processes when CPM fails. Its approach considering singular discrete activities out of the concept of workflow, make it unfeasible for scheduling under the lean thinking perspective. In this case, the construction costs and duration will be determined by the next factors (Kang et al., 2001):

- Physical working areas.
- Crew design.
- Size of the repetitive process or activities.
- Frequency of the repetition for each operation.

A characteristic that makes CPM not suitable for its use in lean construction is its deployment of resource management. The CPM algorithm does not consider the creation of a workflow along the project processes. Thus, resources are established according to the defined duration of the activities under consideration. To do so, resources may be incorporated (Lowe et al., 2012):

- Taking into account the logical restraints that may establish a preferred sequence of work, given for instance by the contractor's crews physical limitations.
- Using resource leveling to take into consideration the resources availability and other resource management constraints.

Even though these two possible ways of implementing resource management, the sequence progression between the activities (considering progression of repetitive activities) cannot be ensured as a smooth one, which may have consequences as idle time for crews, materials or equipment. There is the possibility of establishing a sequence of specific activities due to the mentioned crew constraints, but this does not mean that there will be continuity in the sequence, even if this is performed by the same crew (Lowe et al., 2012). Therefore, since lean construction is strongly based in the pursuing of the perfect workflow in the different project processes, other scheduling methods which consider the optimization of their flows will be more suitable than CPM as, for example, LBMS.

Also related with the concept of workflow, the way in which CPM considers the float between the activities is not appropriate. Float is the time used as a contingency in a path of activities. The total float is defined as the time an activity start or finish can be modified without impacting the project completion date. According to this, CPM considers that the float can be used by non-critical activities, given that the critical path method will be so as it has no float and the minimum scheduling flexibility (Lowe et al., 2012). This way of treating the float is only possible if continuity of tasks is not under consideration. If a continuous flow is required, then it may be needed to include non-critical activities in the chain of activities determining the total project duration, thus becoming critical.

3.2 TRADITIONAL RESOURCE PLANNING IN PROJECTS

A very important part of project scheduling is the resource usage planning, which constitutes a great challenge in every single case. A construction project represents an endeavor integrated by many different elements with a high level of complexity and uncertainty in the processes involved. Therefore, the resources needed will be of very different nature (depending on their skills), characteristics and amount according to the activity they will be used for. Among the considerations to be taken into account when setting the resources are the activity features, resources availability, time frame available, labor rates etc.

The goal when planning the project resources is to ensure enough resources so the project will be performed under its quality, time and costs constraints, which means that a balance between these requirements and the resources availability should be achieved (Meikle & Hillebrandt, 1988).

A common way of graphically represent the resource allocation and its subsequent leveling is with the use of *histograms* or *resource-loading charts*. These are two-dimensional charts considering time and resource usage. Thus, it is easy to see the amount of resources used in each time period of the project (Pinto, 2012).

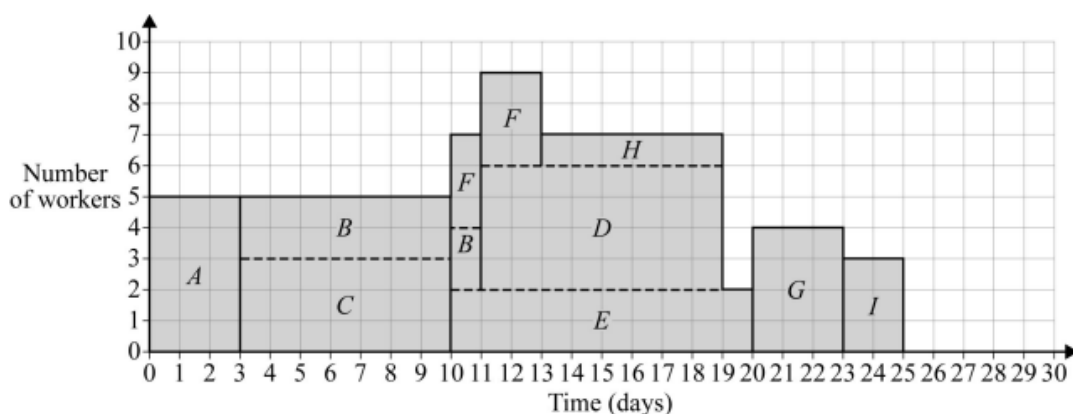


Figure 5 - Resource histogram with workers allocated to tasks A-I (The student room, 2011)

Traditionally, resource planning has been done according to the next process (Meikle & Hillebrandt, 1988):

- The basis taken is the industry demand in economic terms, which will determine the number of units (individuals) needed to perform a task.
- The resource coefficients are used to set the real labor rates for a given task. These coefficients are applied to the total demand to obtain the demand for resources.
- Then, the resources availability is determined.
- Finally, the deviations over the calculated resource values have to be corrected by modifying the available technologies to cope with the demand levels.

This method is based in the use of existent data as the current resources demands or the labor coefficients. Particularly the latter ones are not always accessible and it is difficult to extrapolate the data from one project to another. The availability of this data differs also from one country to another. Specifically in Norway in the 80's, the Central Bureau of Statistics covered this point creating tables where these coefficients were available for different kind of construction projects (Meikle & Hillebrandt, 1988).

3.2.1 Resource allocation and resource leveling

There are many concepts associated with the establishment of the resource planning in a project. Two basic ones are the allocation and leveling of resources, which should not be confused between each other (Hegazy, 1999):

- Resource allocation: also known as resource loading is the process which aims to reschedule the project tasks so a limited number of resources can be used trying to keep the project duration as short as possible given the unavoidable fact that this one will be affected.
- Resource leveling: also known as resource smoothing, aims to reduce the resource variations trying to keep a uniform distribution in the resource demand histogram while keeping the original planned project duration.

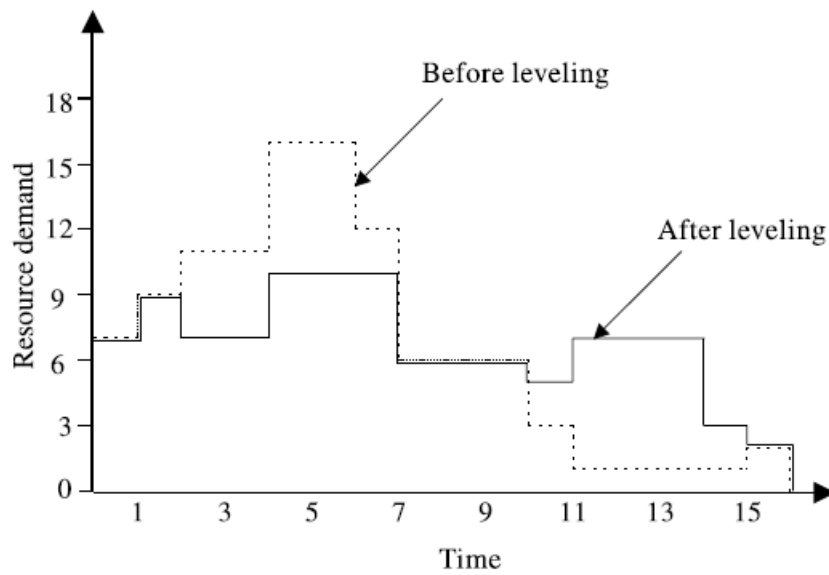


Figure 6 - Resource allocation before and after leveling (Harris, 1990)

3.2.1.1 Analytical versus heuristic models

Another distinction worth to be established is the one between the possible approaches of the existent traditional methodologies (Hegazy, 1999):

- Heuristic methods: these methods use a collection of rules (heuristics) based in logical relationships in connection with the resources' constraints to be applied, to find the desired solution. Some advantages of these methodologies are their simplicity to be understood, easy application and cheap deployment in computational solutions. However, their effectiveness in optimization of the solution could be criticized given their use in logical network scheduling methods, since there are not specific guidelines to choose the appropriate heuristics to be used. One of these methods is the *Minimum Moment Algorithm* (Harris, 1978), which is used to minimize the daily resource usage fluctuations, keeping the project duration unaffected.
- Analytical methods: are those approaches using mathematical or algebraic analysis. This makes possible an optimization of their solutions given the possibility of using maximization/minimization of the considered metrics to

reach the most suitable solution. These methods are more suitable than those based in heuristics when it comes to optimization of solutions, especially when using programming. Some of these methods are the *Genetic Algorithms (GA)*.

3.2.1.2 Deterministic versus non-deterministic scheduling models

When considering project planning it is needed to define the approach in terms of considering or not the uncertainty of the variables involved. This will also influence the way in which the resource plan is set in a determined project. When dealing with resource leveling it is important to acknowledge the physical constraints of the resources in order to avoid fluctuations in the resources demand, which in an ideal situation would be represented by a regular histogram. This means that a resource flow could be established if the same resources change of activity once finished the previous one.

Traditionally, CPM has been used when planning using a deterministic perspective where activities' durations are fixed. Hence, uncertainty in both activity duration and resource leveling are neglected and the solution reached is not realistic. To get a representative solution for both scheduling and resource loading it is needed to consider a non-deterministic approach dealing with the project uncertainty. Moreover, this allows the planners to use probability and fuzzy theories to reach the project distribution descriptive values, which implies a great amount of information in statistical terms. Among the tools that can be implemented in this matter are simulation models as *Monte Carlo* or the so-called *Genetic Algorithms* (Leu & Hung, 2002).

Monte Carlo simulation is a probabilistic tool, which uses an analytical basis to reproduce the outcome of a determined system providing a foundation for, for example, decision making. In this case, the system which behavior is to be imitated is the project, which itself comprises a great number of stochastic variables defined usually by a mean value and a variance representing the uncertainty of the mean value. The simulation allows the user to obtain the solution for a determined variable dependent of the mentioned stochastic features of the project. Thus, the simulation can be repeated n number of times and with these n different results is possible to calculate the most likely value to occur for the phenomenon under study (Vatn, 2008) (Leu & Hung, 2002).

Other tools frequently used for resource leveling are the Genetic Algorithms (GA). The concept itself is based in an analogy with the biological concept of genes. These ones are a string or information sequence, and according to the theory, the quality of the genes of a parent will determine the quality of the genes of its offspring (Leu & Hung, 2002).

The GA's work using two main elements: chromosome structures and GA operators. The first ones are the items containing the information as a string, which in this case could contain information about CPM calculated early starting dates, late starting dates etc. of a determined solution. The latter are the mechanisms that allow the combination of different chromosomes (different project solutions) which will result in the offspring chromosome (Leu & Hung, 2002).

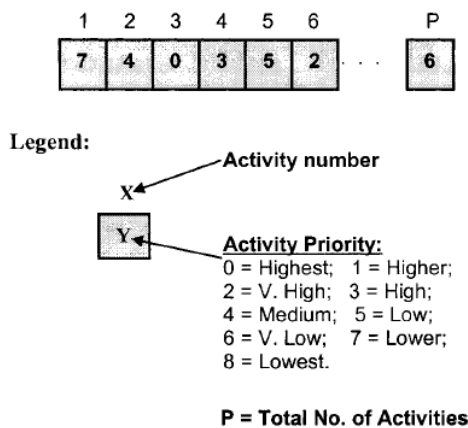


Figure 7 - Gene formation (Hegazy, 1999)

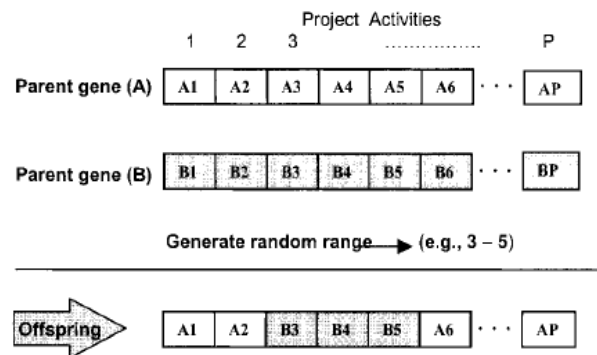


Figure 8 - Generation of the offspring solution (Hegazy, 1999)

3.2.1.3 The limitations of the logical network methods

The commonly used methods of CPM and PERT base their practices in the assumption that resources are available when needed, which does not represent a real project. The result of allocating resources based in this starting point comes often in form of fluctuations, which lead to inefficient and costly resource usage, and unreliable scheduling (Kastor & Sirakoulis, 2009) (El-Rayes & Jun, 2009).

The traditional leveling methods implement the use of the available float between non-critical activities trying to keep the original project duration. The result is histogram profiles difficult to achieve where only certain resources are favored, given the penalization of others to reach the desired profile. Some authors have claimed that the creation of new metrics to evaluate the histogram shapes when leveling resources are needed. In addition, these metrics would solve the limitations of the existing ones and will help to generate more optimal resource schedules (El-Rayes & Jun, 2009).

These new metrics are the Release and Re-Hire (RHH) and the Resource Idle Days (RID):

- **RHH:** evaluate the periods of different resource demand to quantify the resources that need to be temporary hired or released according to the high or low demand level.
- **RID:** measures the effect of undesirable fluctuations and the impact in nonproductive time.

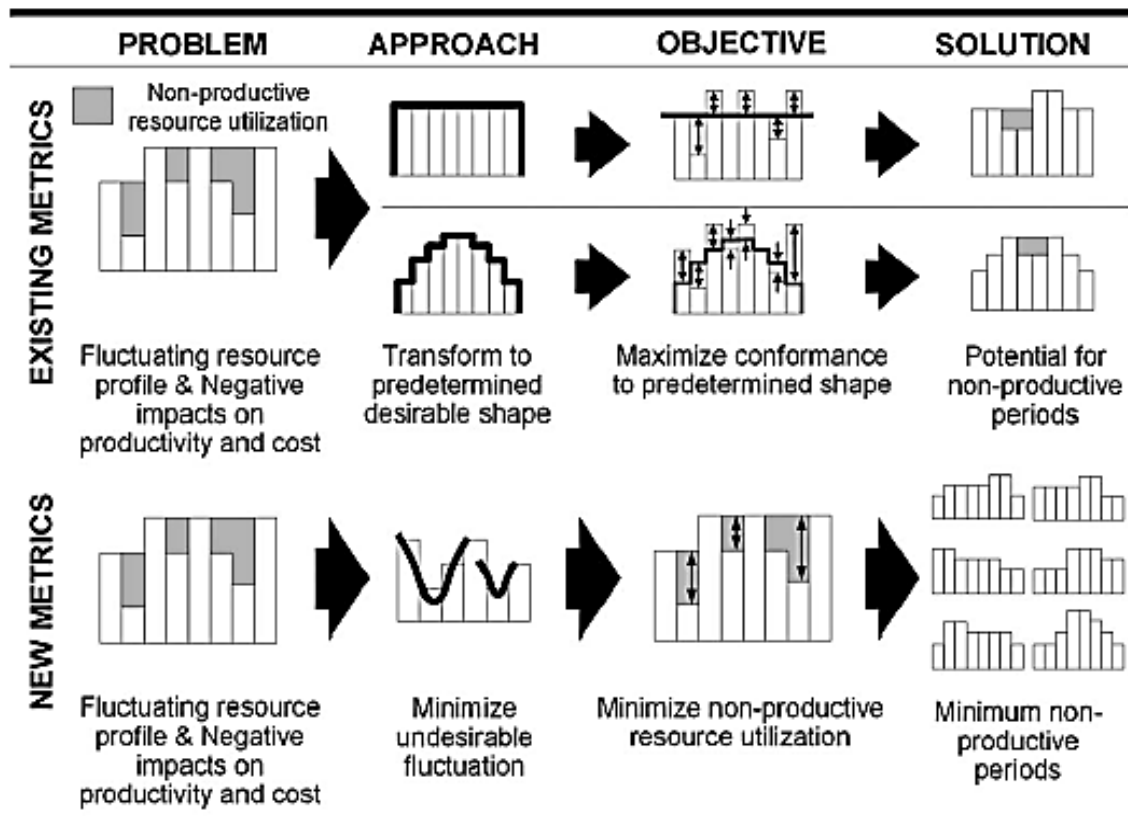


Figure 9 - Resource leveling solutions using existing metrics (El-Rayes & Jun, 2009)

Given the focus of this master thesis on location-based scheduling methods and their principles, it is remarkable the lack of the concept of labor flow in the traditional resource planning methods. These methods present limitations both in allocation and leveling of the resources. When it comes to allocation, either the project locations or the workflow are considered, therefore neglecting completely any flow of the resources and just considering the availability of the resources for the activities at a given time. On the other hand, when considering the resource leveling, if the resulted histogram is such as the resources levels are kept constant (which might be just an ideal situation) it is still not addressed the constant levels of resources from one activity to the next one, so the prerequisites to establish the resources flow is not met. These issues are better examined when planning resources using the LBMS, as it will be further explained (see *3.4.4. Resource loading and leveling*).

Some researchers have reached the conclusion that CPM disregard the problem of continuous usage of resources in its methodology (Harris & Ioannou, 1998). Normally, resource allocation is performed so the maximum number of available resources is established. The tasks are subsequently scheduled when this crew constraint can be met. As result of this requirement, the critical path may be longer and the float in non-critical path activities may be reduced, eventually affecting the critical path as well. Therefore, resource usage in CPM is often discontinuous, and it lacks the capability to ensure a smooth transition for the crews between repetitive activities.

3.3 HISTORY AND DEVELOPMENT OF LBMS

As it has been already stated, the planning systems can be classified in two groups: activity-based and location-based. Their history and development has been linked along the 20th century.

Activity-based methods have been the mainstream when it comes to project planning, but as also seen previously, it does not mean that they are optimal methods. Many

authors have questioned their use, in particular when seeing these ones from the lean production perspective. Hence, their main flaws are:

- Failure in applying the concepts of workflow and continuity.
- Unreliability in projects with a high level of repetition and standardization in their activities.

As a result for this disconformity with the activity-based approach, began a more deep development of the location-based methods. In the second half of the 20th century is when the focus in research became more intense, but even though, just a few commercial applications were made available for its implementation in the construction sector.

Especially in Finland is where research about location-based management systems started to achieve results. During the 80's, the Construction Economics Laboratory in Helsinki became the epicenter of the research, which was initially aimed towards the location-based production control. After the analysis of many successful and failed projects, the main result was the need to focus in scheduling monitoring and control. According to this, planning and controlling should be undertaken as two complementary parts. Planning itself is not enough if the plan is not followed up, it has no meaning. The main results of the study developed in Helsinki by Juhani Kiiras would lead to a white paper about planning of initial schedules, published in 1989 (Kenley & Seppänen, 2009a).

The main results of the study are:

- Production control is more important than planning itself.
- Controlling requires good schedules, continuous monitoring and quick actions against deviations.
- The schedules have to be feasible in terms of time, cost, and resources availability and capacity.
- Planning and controlling have to be undertaken according to zones of the project (this will lead to the location breakdown structure).

- Continuous production is essential for the good implementation of the plans (related with the lean principle of workflow).

The term location-based scheduling was first coined in 2004 by Kenley (Kenley & Seppänen, 2009a). After its establishment, there have also been created different tools to support the location-based scheduling methods as the software VICO Control Software, which development started in Finland by Olli Seppänen.

Nowadays there is an increasing number of users of location-based planning schedules due to the acceptance these methods are acquiring. A better understanding of the nature of the construction projects, their needs and requirements have come together with the acknowledgement of the benefits that a shift from the traditional project management to the new lean perspective could bring. Thus, the need for the implementation of the location-based methods is continuously arising.

3.3.1 Relation of LBMS with Lean construction

Location-based management systems are directly related to lean theory since they share the same basic principles of minimizing the waste, increasing productivity and decreasing variability.

Lean thinking was developed in the 50's by the Japanese car manufacturing company Toyota, and gradually has been adopted by other kind of productions, included construction. From the early 90's researchers started to look upon this new production perspective and its suitability for construction (Koskela, 1992). This happened as a response to the non-fulfilling traditional construction approach. The characteristics of the construction projects as unique, complex endeavors with high uncertainty levels made impossible for this traditional perspective to accomplish the minimum requirements in cost, time, quality and value creation towards the project stakeholders.

Given the common principles shared by LBMS and lean production, there is a difference in the interpretation of flow. LBMS considers a task as a collection of related activities, which are to be executed according to a continuous production through a set of different

locations. Thus, the focus is in the labor flow that is required to happen by completing the project locations in a sequential way. Hence, the locations and their individual features are the pulling system for the flow and resources. On the other hand, lean production focuses in the workflow given a sequence of different trades between different experts. Therefore, the completion of one trade pulls the start of the next one. This means that in LBMS the same crew or resources undertake a whole task, meanwhile in lean production there may be several resources involved to accomplish a task.

A construction project can be interpreted as a production chain integrated by different flows. The two core flow processes are the *design* and the *construction* processes (which involves the materials and labor flows) which are complemented by others as the control and support ones. There are seven project features, which understood under the flow perspective act as the preconditions for project planning (Koskela, 2000):

- Information flow
- Work flow
- Material flow
- People flow
- Equipment flow
- Space availability flow
- External conditions

Each flow represents a process with characteristic cost and duration, and will introduce in the project outcome certain value for the customer. The cost and duration will be determined according to the efficiency of the activities in the project, considering the value-adding ones and also the non-value-adding activities (Koskela, 1992).

3.3.1.1 Integration into a management system

A main feature of the LBMS is the focus in production and its improvement by reusing data, or in other words, by accomplishing an iterative process. Historically, the management methods used in the construction industry did not contemplate the reuse of data connected with an internal benchmarking. This means that every input is a singular data entry in the management system ignoring the impact on the current

productivity efficiency of the construction process, and its possible enhancement. Thus, these methods are not suitable to solve lean production processes. LBMS has the mechanisms to undertake the iterative process needed in lean construction (Kenley & Seppänen, 2009a):

- Documentation systems aimed to represent accurately the items to be built. The design model is so that each element is linked to a hierarchy of locations (LBS) which integrates the data making possible its reutilization.
- Measurement systems where objects are measured related to its location and including information related to its production.
- Estimating systems based on the relation of the objects and their location quantities, which using previously known rates are able to find the normal and optimal production estimations.
- Production planning using flowline scheduling representation, linking activities with locations. This information is integrated with the quantities and production information as well.
- Progress forecasts and control according to the established current production rates.
- Visualization in a 3D geometry model extended to a 5D model with time and cost included.

3.3.2 What is a LBMS? Main elements of LBMS

'The location-based management system (LBMS) is an integrated network of management system components potentially involving all stages of construction, from design through to completion' (Kenley & Seppänen, 2009a). The consistent use of this system in a project allows to lower its costs, improve its constructability and reduce its risks. This system uses locations as analysis unit based in the concept that building projects is seen as a series of physical locations in which work of different type and quantity must be completed (Kenley & Seppänen, 2009a).

Similar as in a work breakdown structure (WBS), a location breakdown structure (LBS) serves as a work division to the lowest level of detail of the project. When working with a LBMS, the information is gathered in a hierarchical system where locations are the smallest elements and, as we move to higher levels, these will integrate the information stored in the lower ones.

A location as unit contains the next information:

- Building objects or components (elements and subsystems) which should be documented as 3D geometry objects.
- Planned and actual building component quantities which will be measured in the 3D model preferably.
- Building system production assemblies and the selected construction method.
- Planned and actual material costs.
- Building system costs aggregated iteratively for each location and hierarchy level within the LBS.

The unit of control is the task and contains the information regarding project production as labor resources, time and cost. In this case, a task is the element that aggregates all the activities of the same kind that will be repeated in different locations. The task is defined and belongs to a hierarchy level of the LBS, i.e. a determined task will be performed in a subsequent series of locations which might be the floors of a building (the floor would be the hierarchy level).

The task contains the next information (Kenley & Seppänen, 2009a):

- Standardized production data as consumption rates for ideal crews and resources which will be used in the resource planning.
- Planned and actual resource requirements.
- Work crews. Structure and number of crews for the plan and actual work.
- Logical constraints related with the logical relationships established in the CPM, in which relays in part the LBMS logic.
- Pre-requisites for production as procurement, precedents, materials supply etc.
- Performance and forecast to estimate the future progression of the task.

When it comes to the logical constraints under the LBMS, it is noticeable that it does not ignore the CPM logic, but it applies a five principles of *layered logic* at the activity level based in the CPM logic.

These five logical principles are:

1. External logical relationships between activities within locations.
2. External higher-level logical relationships between activities driven by different levels of accuracy.
3. Internal logic between activities within tasks.
4. Phased hybrid logic between tasks in related locations.
5. Standard CPM links between any task and different locations.

The layers 1, 2, 4 and 5 refer to physical restraints meanwhile the layer 3 defines the workflow and sequence of work within the task. It is important to notice that layered logic is not hierarchical but applied likewise. This creates the need for the forward and backward passes to compute the CPM method (Kenley & Seppänen, 2009a).

The LBMS is different to CPM also in the use of time buffers complementary to the logical relationships between activities, tasks and locations. Two elements refer to the added durations apart from the duration of an activity itself. These are (Kenley & Seppänen, 2009a):

- *Lags and leads* (used also in CPM): are the fixed duration of a logical connection between two activities or tasks.
- *Buffers*: time required to absorb the disturbances and thus protect the Schedule from production variations.

3.4 FLOWLINE SCHEDULING

The main principles in which location-based scheduling is based are those resultant of the research made by Juhani Kiiras in Helsinki in the 80's. The next are the key principles he described as the basis for successful scheduling (Kenley & Seppänen, 2009a):

- Duration should be calculated according to good target productivity rates.
- Buffers protect the schedule against unforeseen events.
- The production rates can be synchronized changing the size of the crews.
- Each location has only one task assigned at the time.
- Subcontracted tasks should be planned according to project quantities and established productivity rates.
- Crews should not disturb each other; they could use free locations corresponding to buffer times.
- Tasks out of the schedule should have resources allocated.

These principles are the basis of the location-based scheduling using flowline representation charts. This scheduling method and its elements will be further described in this section, especially in relation with one of the current available commercial solutions: VICO Office.

When facing the scheduling of a project there are certain requisites about information that should be available in forehand before attempting to plan anything:

- Information about the context of the project as the place where it will be located, its surroundings, the stakeholders, the use of the final product once delivered etc.
- Contractual aspects of the project that will determine the resources availability: budget, subcontracts or materials (Bill of Quantities).
- Project calendar, when the design and construction processes will take place.
- Physical characteristics and geometry of the project (3D model), in other words, what is going to be built.

The information about the next variables should be clearly established in order to be able to undertake the progress planning of a project. Thus, a realistic result could be reached (Eikeland, 2009):

- Start / End
- Duration
- Available resources
- Dependencies
- Activities uniformity
- The project's character
- Locality
- Complexity Degree
- Geographical repetition / uniformity

After gathering this information, and once decided the scheduling approach to be used, it is possible to start planning the project schedule. In this case, the methodology to be followed is the location-based scheduling under the lean construction principles. The result will be a flowline graphic representation with the expected project progress.

3.4.1 LBS - Location breakdown structure

As the focus in this planning method is to take the locations of the project as unit of analysis, the first step is to establish the hierarchy of the project locations. Thus, the LBS will determine the appropriate level of precision to assign the project information as quantities or resources. Each location will be unique due to its position in the project geography and stored information (VICO Software, 2008).

The different levels of this hierarchy contain the different physical units compounding the project. For instance, in a residential project containing three blocks (AD, EH and IJ) of approximately similar physical characteristics, the highest level would contain the

three different blocks, the next lower level would contain the ten sections from A to J, and the lowest level would contain the floors in each building within each section.

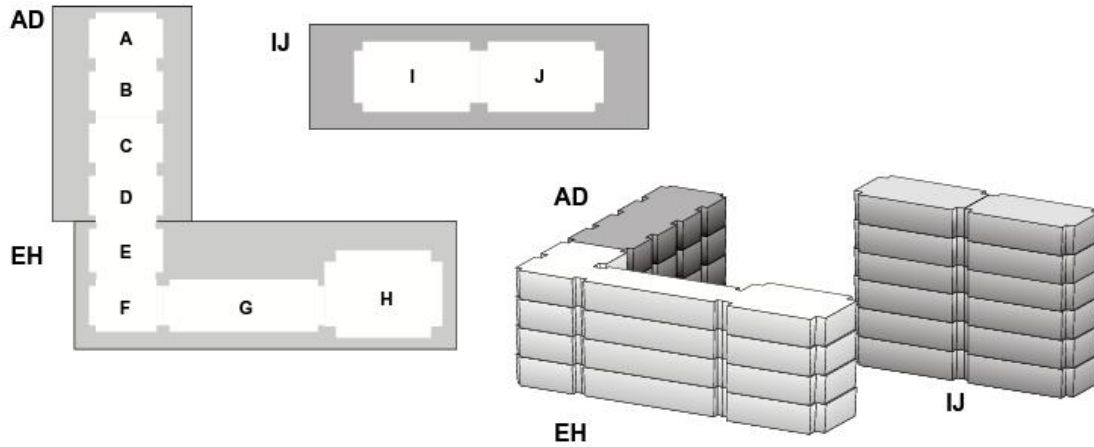


Figure 10 - Schema of a residential project with 3 blocks (Kenley & Seppänen, 2009a)

When defining the different levels or locations in the hierarchy, these must follow a certain criteria (Kenley & Seppänen, 2009a):

- The highest level should contain structures independently built from the others, as buildings, or big parts of large buildings.
- The intermediate levels should be settled according to the workflow in a logical way for the tasks that will go through. This will be represented in the vertical axis of the flowline.
- The lowest levels should be such as their extension and position facilitate the progression of the project according to the established working rates and defined crews, and facilitate monitoring and controlling.

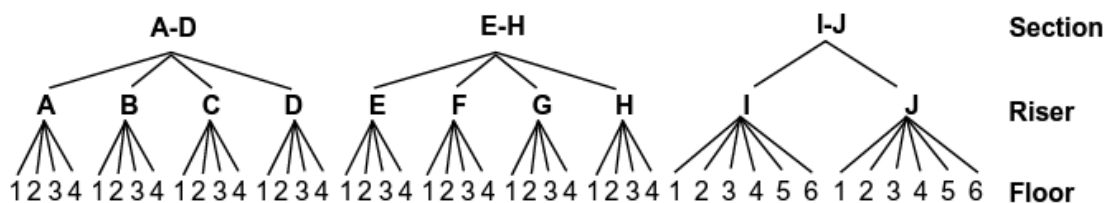


Figure 11 - Hierarchy in the LBS (Kenley & Seppänen, 2009a)

The information each unit/location contains is (VICO Software, 2008):

- The name of the unit, which should be such to avoid confusion with other units.
- The quantities expressed in area units (m²).
- The number of subunits or locations in a lower level it contains.

3.4.2 Location-based quantities

The bill of quantities (BoQ) of a task defines the work that has to be performed in each location. A task is defined as the group of related activities that a crew will perform along subsequent areas of the project. The different activities' quantities collected in a task may be different according to their nature, measuring units, and quantities which may vary for different locations.

Establishing the quantities is the next step after the LBS when planning using VICO. Given the BoQ of the project, it has to be divided in packages that will be performed by a single crew, following the logic established in the LBS for their realization, and which can be finished in one location before continuing to the next one (Kenley & Seppänen, 2009a).

The task quantities will be calculated according to the consumption rates, which will be constant within each location (lowest level of the hierarchy). These rates may be obtained from historical data, but it is needed to take into account the specific features of the project before applying them. Given the information about consumption rates, resources (crew design) and productivity, it is possible to calculate the duration of the activities.

As pointed in the previous point, the quantities will be stored as part of the locations data with their corresponding measuring units.

3.4.3 Task definition

Once the units of analysis have been defined with their required information about their physical location in the project, hierarchy level and quantities, the tasks can be established. A task will set the flow of related activities going through the project locations. According to VICO, it is possible to define three types of tasks (VICO Software, 2008):

- Schedule tasks: define the combination of resources consumption and required work over all the locations.
- Procurement tasks: sequence of preparatory activities previous to the schedule tasks (design, tendering, manufacture or materials delivery).
- Overhead tasks: virtual tasks using costs and resources time-related to schedule tasks.
- Workable backlog (planned work complete): tasks used in case of gaps free of activity in a crew working sequence so it keeps its workflow. These tasks are planned after the rest of the tasks have been set and its aim is to avoid unnecessary stops that would lead to ineffective use of the crew available working time in the project (Kenley & Seppänen, 2009a).

The definition of the tasks in relation with the other tasks within the project is done through the layered logic based on CPM. In the most simplistic approach, using only the first three layers, a task can be defined taking into account its internal work sequence through locations (given by layer 3). The layers 1 and 2 set the connection between the tasks passing through the same location, for the same and higher hierarchical levels, respectively. If taking into account different locations, the layers 4 and 5 should be considered, setting the relationship between the tasks in the different locations.

Another aspect that makes location-based scheduling different from the CPM methods is the different treatment the activities receive given the three established kinds: *schedule, procurement and overhead tasks*. Meanwhile in CPM there is not discrimination between activities and all are treated as equally important for the production, in LBM the activities are handled and scheduled differently with the aim of achieving the highest degree of production continuity.

3.4.3.1 Procurement tasks

Procurement tasks in LBM are treated as prerequisite for schedule tasks. There is a greater emphasis in the importance of the schedule task itself but keeping in mind the need to establish the conditions for the successful development of this one. Thus, procurement tasks are scheduled after the schedule tasks are set. So according to the lean production philosophy, procurement and design tasks should be scheduled using pull scheduling techniques. According to this approach, workflow in production is essential and therefore this production is the pulling mechanism for the procurement tasks. A common practice is to use backwards planning (see 4.3.2 *Backwards planning*) to establish the link among the procurement tasks that may precede a schedule task. Quantities can be also used to link a procurement task to one or more schedule tasks. (Kenley & Seppänen, 2009a) (VICO Software, 2008)

A procurement task is composed by the activities (from materials organization to subcontracted work) which can be ordered from the same supplier. These tasks have an estimated lead-time and must be completed before the related schedule tasks begin. Procurement tasks normally include:

- Design
- Plan of the schedule task
- Documentation and call for tenders
- Bid evaluation
- Contract
- Delivery order

It is noticeable that design in a project can be of a complex nature and therefore is considered with especial regard. Design can be set between procurement planning and production planning depending on its level of detail. During procurement, design with a low level of detail should be available before calling for tenders to establish the basic physical features and requirements of the project. A more detailed design will be given during the production planning phase. This is normally undertaken as an iterative process where the designed elements will set in part the conditions for the schedule tasks to be planned (Kenley & Seppänen, 2009a) (VICO Software, 2008).

3.4.3.2 Overhead tasks

Overhead tasks are virtual tasks related to the cost and resource use in connection with the schedule tasks. They are established as a function of their duration and their unit price. The cost of these tasks is normally incurred by the general contractor. These tasks are the equivalent to the *hammock tasks* in CPM, which are a summary task which collects the total duration from the start of the first subtask to the end of the last one, given a set of multiple related subtasks as the use of cranes or other site equipment, supervision, etc. The peculiarity of these elements is that they have a daily cost regardless of their use (Kenley & Seppänen, 2009a) (VICO Software, 2008).

3.4.4 Resource loading and leveling

The impact of continuity in the critical path and the total float is a main point in LBMS resource planning and will condition which activities become critical. LBMS deploy resource allocation with the aim of reaching a continuous resource flow with the appropriate production rates (Lowe et al., 2012).

There are some aspects that differentiate resource planning with LBMS from the traditional methods linked with the logical network approaches (VICO Software, 2008) (Kenley & Seppänen, 2009a):

- As the project locations are the units of analysis, their characteristics will define the maximum number of resources that an optimal crew should count on for an appropriate performance.
- The schedule tasks are defined by the quantity of work and the resources consumption for all the locations in which the task will take place, which are used to compute the resources needed.
- The resources should be allocated given the optimal crew design and number of crews required realistically, given the available hours of the established working day (for example 8 h per day).
- The optimal rhythm for working or '*takt*' should be taken into consideration. This concept is related with the constant working rate the project tasks must follow

to keep the workflow. Some researchers have compared the flow the tasks follow over the project location with a train movement where the 'takt' rhythm is equivalent to the train speed (Skaret, 2012).

- The layer 3 of the layered logic set the relation between activities within tasks, leveling the resource consumption within a task. It may be the case that the same resources are shared between different tasks, which will require additional leveling methods. This extra leveling is similar to the layer 3 logic but it requires forcing a continuous consumption sequence for a given resource (Kenley & Seppänen, 2009a).
- Collaboration between the planners and subcontractors involved is crucial to assess the tasks durations and risks, and therefore allocate the necessary resources (Kalsaas et al., 2010). It is a normal practice to have backwards planning sessions and other meetings among the parts involved to undertake this.

3.4.5 Flowline representation vs. Gantt diagrams

A common way project schedules have been commonly visualized is with the use of graphical tools as flowline or Gantt diagrams. In the last century Gantt charts have been widely used for project planning and are still among the most implemented tools in project management, for construction and other kinds of production. With the development of the location-based management systems in construction, there have been an increasing need to develop a tool which could handle the information regarding the location where the tasks will be performed. The result has been the development of the flowline representation system. Below the different aspects of these two diagrams are exposed together with their advantages and disadvantages.

3.4.5.1 Gantt diagrams

These representation system takes its name from Henry Gantt, who published '*Work, Wages and Profit*' in 1910 where he presented the diagram for first time. However, he was not the first author reaching this graphical solution. By the end of the 18th century,

Karol Adamecki had already developed a similar solution to the Gantt diagrams, even though he did not get the recognition for this discovery (Eikeland, 2009).

A Gantt diagram is a graphical chart of a project where the activities are represented as horizontal bars with a length according to their duration, which is shown in the horizontal axis following a linear representation. It can also show information as the project milestones, dependencies between activities or allocated resources. Therefore, it allows the users to get an overview of the project plan. Normally tasks are grouped in categories where each category can be used as a summary task of the tasks it contains.

When planning using Gantt, the result will be a chart as the following one:

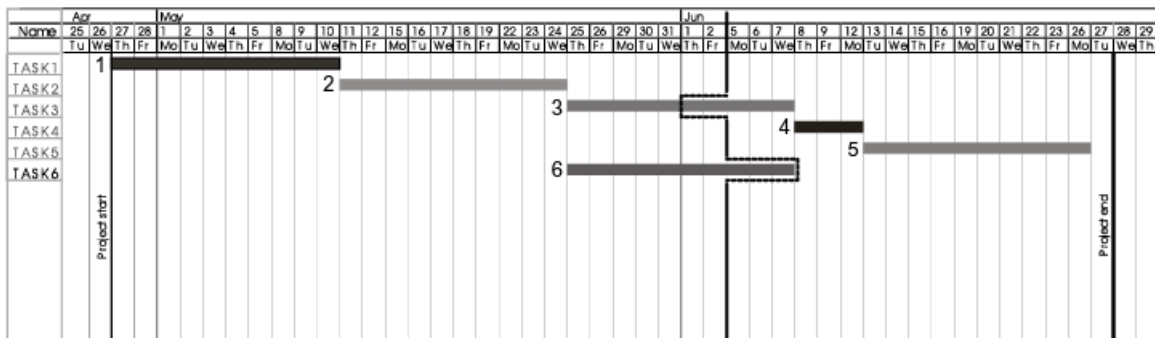


Figure 12- Gantt chart (Kenley & Seppänen, 2009a)

There are two main parts in the representation system (Grover, 2002):

- The left part contains a list of all the activities usually grouped according to their category. Normally tasks are listed in the order they will occur chronologically within each group and the same happens when ordering the groups. Each activity contains also the information related with the variables previously stated as needed before planning (duration, start, finish, resources, dependencies, etc.).
- The right part represents the information included in the left side for each task. It can include also a line representing the current date to evaluate the project progress.

Some of the advantages of using Gantt diagrams are (Kenley & Seppänen, 2009a), (Grover, 2002):

- Most users are already familiar with this representation format.
- Information is easy to understand.
- Time is explicit and linear.
- All tasks are visible in relation to others.
- Deadlines are shown.
- Project status at intermediate times is shown.
- Can show progress by 'filling in' task boxes.
- It is easy to see how the progress of the tasks is, if they are delayed or ahead of schedule.

On the other hand, its disadvantages are:

- Uneconomic way of representation due to the space it requires.
- Need for information to be summarized and include quantities and worker hours in order to have a complete vision of the project status.
- It does not show the effect of deviations in the project.
- It is not possible to differentiate start-up delays, interruptions or slowdowns.
- It is not possible to compare the status of different points in time without using multiple status lines.
- Even though it is possible to use status lines, it is difficult to see the production rates.
- It does not allow making forecast of the production rates.

These kind of diagrams have been criticized lately due to its relation with the CPM methodology as graphical representation. As previously mentioned, CPM has been proven limited in the case of construction projects and therefore the Gantt diagrams are either an optimal tool. A main issue is the difficulty of monitoring the planned use of the resources as the work rates are not fully represented by the horizontal bars (Andersson & Christensen, 2007).

3.4.5.2 Flowline diagrams

A flowline chart is defined by the information and elements explained at the beginning of this section (see 3.4 *FLOWLINE SCHEDULING*). It contains extra information about the location where tasks are to be developed, in comparison with Gantt diagrams. In addition, it is possible to plot the actual progress lines simultaneously with the planned progress, being able to compare them. This allows the user to obtain forecasts of the progress according to the current working rates and monitoring and control become simpler processes.

Summarizing the principles under this graphical representation (Kenley & Seppänen, 2009a):

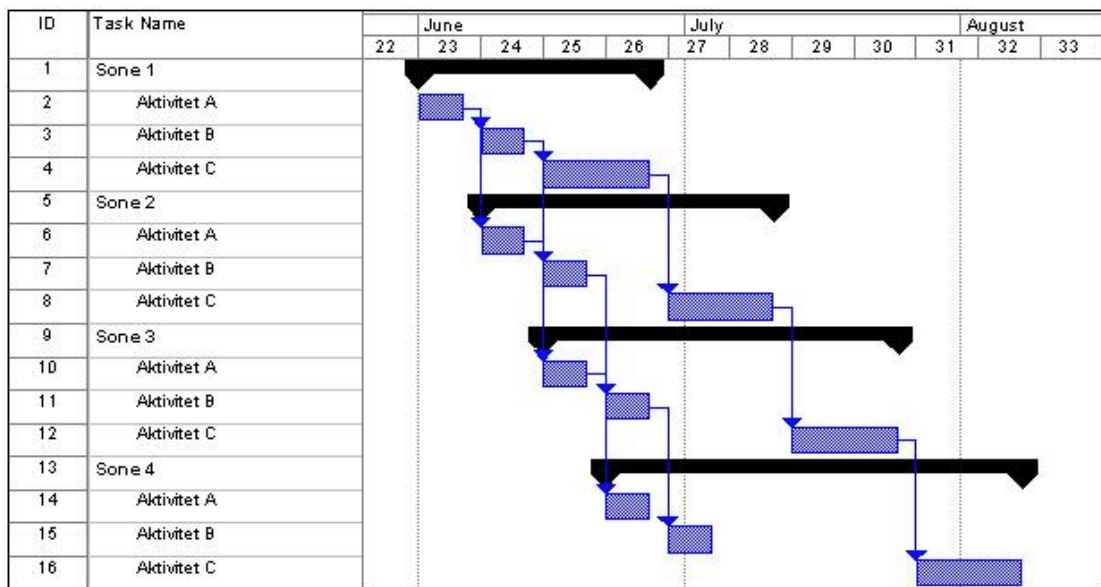
- The lines in the chart go through the locations in which the project is divided.
- When completion rates are not estimated, the line will show the progress by being drawn halfway in the corresponding location.
- Once estimated the completion rates, the actual line can be drawn for the corresponding locations.
- Horizontal lines represent interrupted work.
- The actual lines end at the time and location where the work actually ends.

Some of the advantages of the flowline representation are:

- Intuitive and clear representation of the project plan.
- Efficient representation which occupies reduced space in comparison with Gantt diagrams.
- Allows an historical view of the project without the need of supplementary archives.
- Control and monitoring is a simple process done by showing actual versus planned production to evaluate the effects of deviations based on progress data.
- Shows which locations are free.
- Allows optimization reducing the labor rates in some cases.
- Separates start-up delays from interruptions and production rate deviations.

However, there might be some difficulties when implementing flowline scheduling, especially if the users are used to the traditional planning with CPM and Gantt diagrams (Andersson & Christensen, 2007):

- There might be lack of experience referred to the use of lean construction practices, location-based scheduling or the tools and software to be used, i.e. VICO Office.
- There is a need of setting a sufficient level of detail from the beginning of the planning which might be difficult to be changed afterwards.
- The location breakdown structure might be challenging when the physical features of the locations are very different.
- To keep the established production pace it is needed a certain level of synchronization due to the interdependencies among the project locations. This leads to the use of buffers instead of float time.
- It requires a lot of initial input when using the software tools as the detailed geometry or the bill of quantities, which act as initial point for the planning.



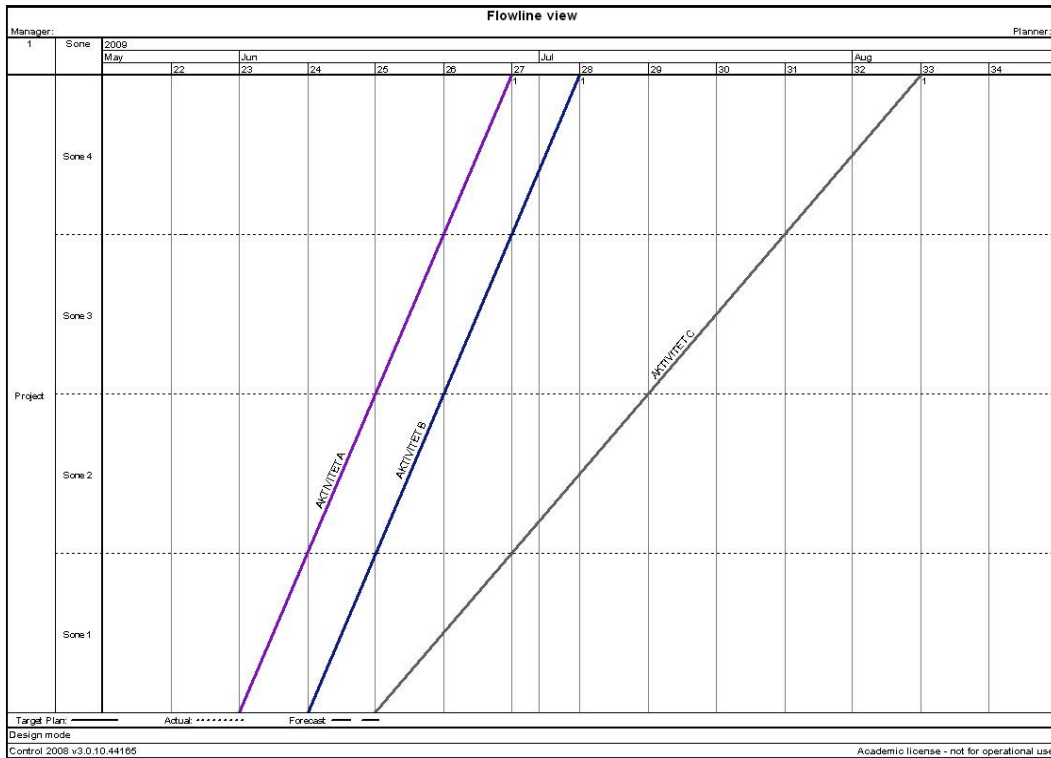


Figure 13 - Representation of 3 activities in 4 different locations in Gantt and flowline charts (Eikeland, 2009)

Given the comparison of Gantt and flowline diagrams it can be stated in three points the major implications of the location-based schedules over the traditional ones (CPM) (Andersson & Christensen, 2007):

- Improved schedule overview: easier way of visualization as precondition for the workflow establishment and the improvement of project control. The overview of the resource allocation allows an easier understanding, which contributes to a better communication between the different subcontractors and stakeholders.
- Establishment of the workflow: using Gantt diagrams it is difficult to ensure continuity of the workflow, but in flowline scheduling it is possible to establish the desired production pace given a rhythm that will guide the resources and their workflow along the project locations. This rhythm is also known as 'takt'. It is also possible to simulate different working sequences which would result in different solutions with different tasks locations/dependencies.

- Improvement of project control and monitoring: the combination of information location/resources/time provides a powerful tool when it comes to monitoring, control, forecasting and comparison of the planned and actual production rates.

3.5 OPTIMIZATION OF FLOWLINE SCHEDULES

Flowline scheduling represents a breakthrough for construction managers in the sense that it allows project planning optimization in a very intuitive and visual way. The next example shows how to improve a sample schedule by aligning the different tasks' production rates. This optimization can be done modifying the next elements:

- Space buffers, which are the locations where work is not being performed between active tasks.
- Adjusting the crew design, adding or subtracting elements from the crew to reach the desired labor rate.
- Adjusting the number of total crews undertaking the different tasks.
- Splitting tasks to be undertaken in a non-continuous sequence or keeping them continuous (Setting the task work continuity as 'Paced' or 'As soon as possible').

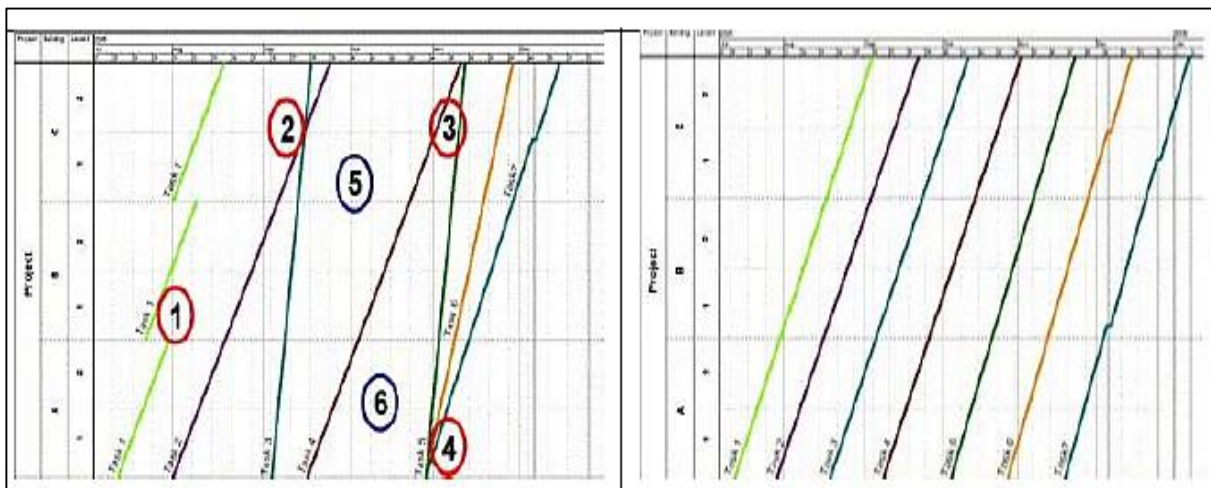


Figure 14 - Comparison of the same project before and after optimization of its flowline schedule (Jongeling & Olofsson, 2007)

In the Figure 14 of the example, several aspects can be improved (Jongeling & Olofsson, 2007):

1. Activities from the same task happening at the same time in different locations.
2. Tasks colliding between each other in a same location.
3. Lack of buffers.
4. Several activities starting at the same time.
5. And 6. Inefficient use of the time/space.

In the right side of Figure 14, it is possible to see the same activities in an optimal plan by aligning the different tasks. In this situation:

- Continuous tasks have the same production durations.
- The produced quantities are the same.
- There are buffers between the activities to prevent collisions in a same location.
- The work is equally distributed along the project time frame, avoiding very critical periods and inactive periods.

It could be said that the problem itself can be solved using a geometrical approach which results imply the modification of the initial values of the project variables. Having the possibility to optimize the schedule using a graphical tool represents a great advantage in comparison with the Gantt diagrams, where it is more difficult to establish an optimization process given the higher complexity that the chart presents for the user.

3.5.1 Project Control

To deliver successfully a project requires more than a good plan. It is essential to develop a control strategy to keep track of the project status, to keep it within its budget and time limitations. Therefore, it is necessary to know what and when is happening at any time of the project. The best way to undertake such exercise is to follow a systematic approach to follow up the project evolution. Actually, control is an iterative process which can be pictured by a cycle made up by four phases (Pinto, 2012):

- Setting the goals which include from the overall project scope (project start and termination dates) to the project baseline plan which collects the goals for each task of the project.
- Measuring progress through mechanisms that allows picturing the actual and forecast progression.
- Comparison of the planned/forecast and actual performance of the tasks.
- Taking corrective actions to minimize or remove the deviations.

There are four main concepts to take into account when following up and controlling a project. These are themselves the information sources needed to implement a good control process (VICO Software, 2013).

- Baseline schedule is the optimal plan established using production rates and historic data together with pull scheduling.
- Current schedule includes any new variable in the schedule as latest design changes or new incoming data.
- Progress data gives the real-time evolution of the ongoing tasks in the project.
- Forecast data represent usually a foreseen project view of two weeks ahead.

In the context of this master thesis, location-based scheduling allows the user to plan the workflow in a project according to a continuous sequence of activities through the project locations, but planning continuous does not ensure that the actual progress will be in this way. One of the main advantages of the location-based scheduling is its improved capacity for project monitoring and control, which makes the project following up much easier for the user. Consequently, the user will be able to take correctional measures if needed by using the graphical representation of the baseline, actual and forecasted tasks' progress.

Figure 15 represents the progress of a task along four different locations. When starting the third location, the labor rate decreases so the actual progress is slower than predicted. According to this new established rate, it is possible to foresee the future progress and compare it with the initial perspectives.

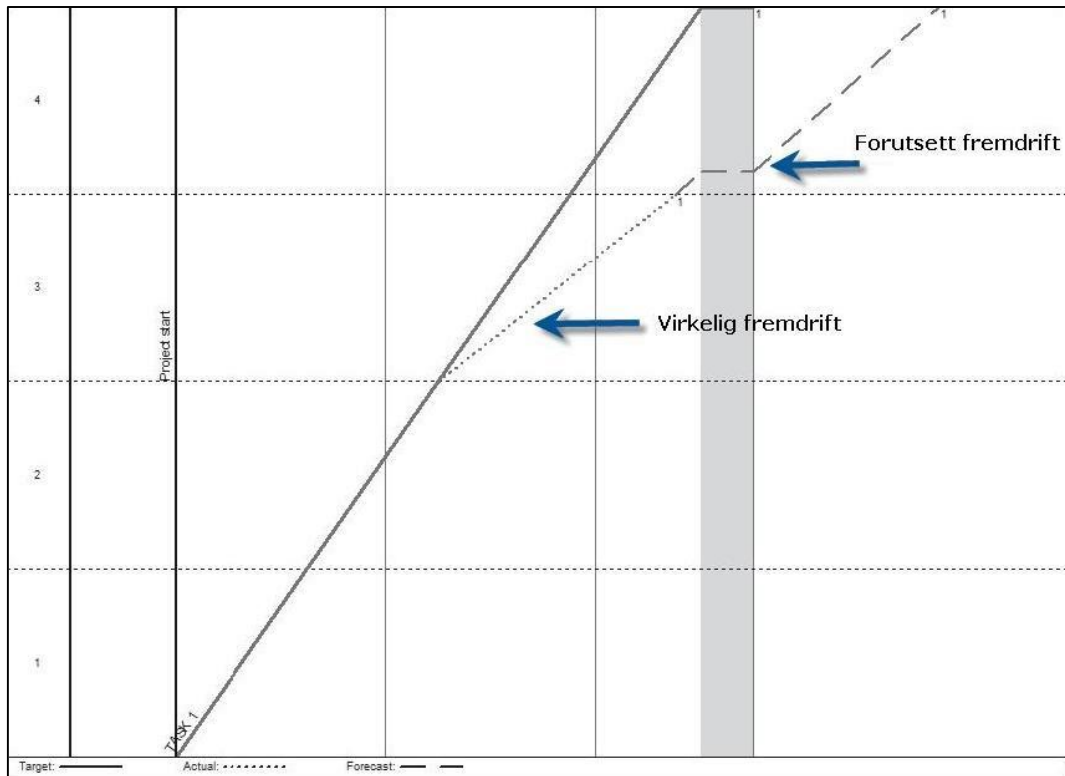


Figure 15 - Planned vs. Actual forecast (Eikeland, 2009)

A main difference of the location-based schedules with the activity-based ones is the unit of control, which in this case is the task. The information that each task contains regards labor resources, time and cost.

There are also different ways to undertake project control. These are:

- ***Proactive control*** aims to ensure a good procurement and production evolution. This is done through the integration of the procurement tasks to achieve the prerequisites established which will assure the production to happen as planned.
- ***Reactive control*** is undertaken after the development of the tasks. It seeks to find the reasons why the plan has not been fulfilled by using tools as root-cause analysis, estimating the total effect of the deviations in the project, and finally taking counteractive actions to minimize or eliminate the effect. Some of these actions might be a change in the resources to increase the labor rates, work overtime, change the tasks' sequence, or establish parallel production in different locations (Seppänen & Kankainen, 2004).

3.5.1.1 Deviation types

Seppänen and Kankainen (2004) classified the possible deviations that may occur in a flowline schedule in four groups. Those can be exemplified with two tasks comparing an optimized situation with task alignment versus a non-optimized situation:

- Start-up delayed of the preceding task: In a situation with aligned tasks, this should not suppose a problem if there are buffers able to absorb such delay. On the other hand, if tasks are not aligned there might be collisions with succeeding tasks, which might require modifications of the schedule.

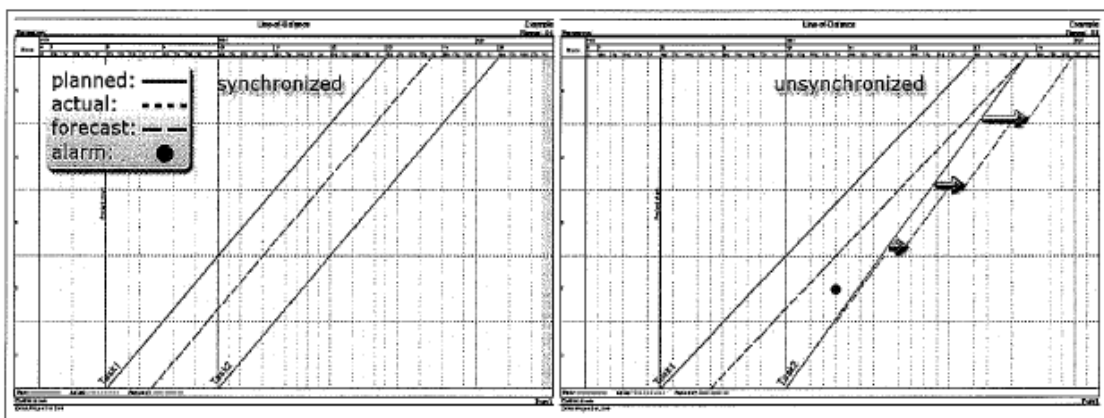
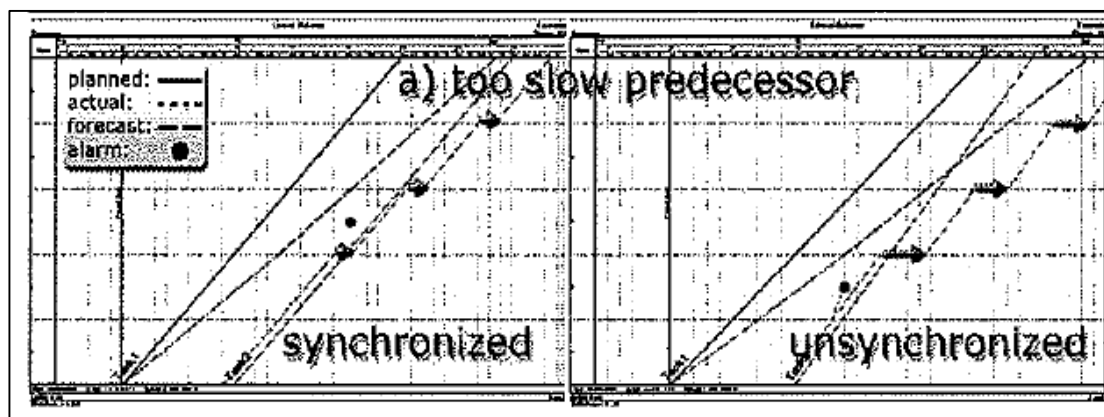


Figure 16 - Effect of a start-up delay in synchronized and unsynchronized schedule

- Change of the production rates with too slow production of the preceding task or too fast production of the succeeding task: This deviation might disturb the continuity of succeeding tasks. To avoid this it is important to found the planning in a good basis about the project quantities and labor use and availability.



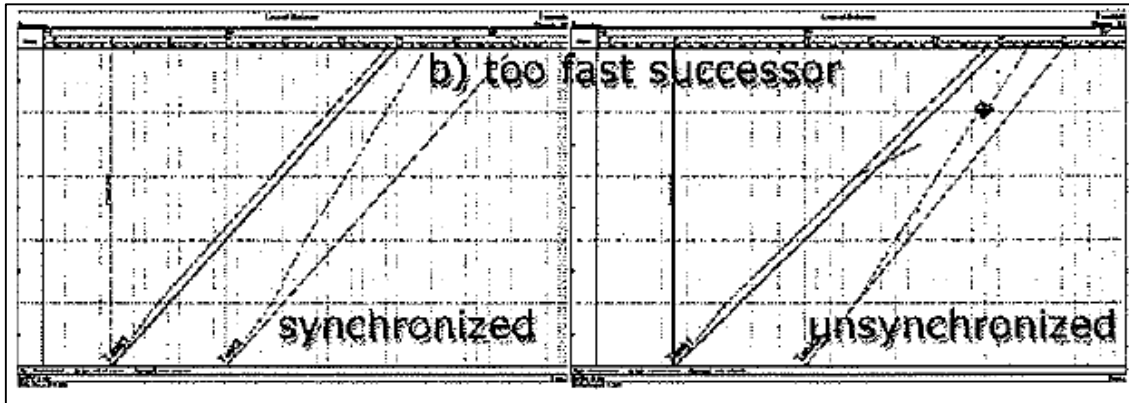


Figure 17 - Effects of too slow predecessor (a) and too fast successor (b) in synchronized and unsynchronized schedule

- Splitting of work to multiple locations at the same time: This makes that resources are divided in different places so continuity is compromised since locations cannot be finished and continued with the workflow. To prevent this deviation it is important to plan carefully the legal agreements with the subcontractors and keep good communication channels with them so they acknowledge the planned schedule and working sequence.

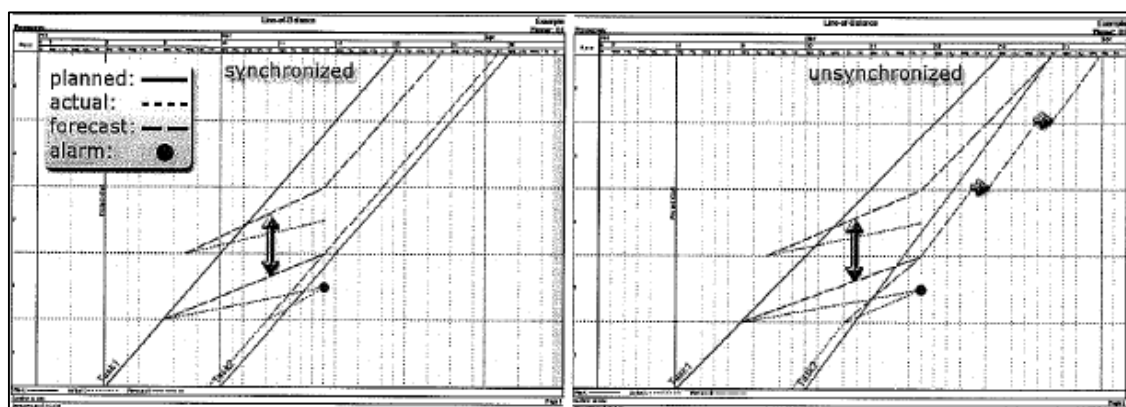


Figure 18 - Effect of splitting work to multiple locations in synchronized and unsynchronized schedule

- Wrong sequence of working locations: Thus, the next tasks planned might be disrupted. To prevent the effect of this deviation, it is needed to study and set the best location sequence for the different tasks according to the characteristics of the project locations.

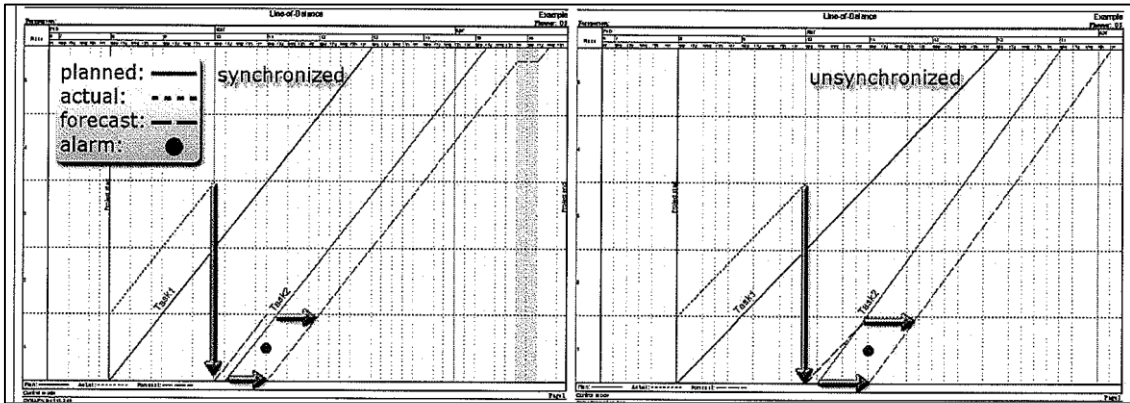


Figure 19 - Effect of wrong order of completion of places in synchronized and unsynchronized schedule

According to the concepts exposed related to project control it is possible to state that (Seppänen & Kankainen, 2004):

- Planning continuous is not enough to ensure the project workflow. To achieve it is necessary to implement project monitoring and control measures.
- Starting tasks as soon as possible (if their prerequisites are not met) may result in posterior slow-downs.
- Splitting work in multiple locations as a control action result in delays and disturbance for the subsequent tasks.
- Overlapping work in locations makes controlling processes more difficult.
- To achieve reliable workflow it is necessary to implement lean theory when planning, especially the pull scheduling mechanisms.
- A combination of proactive and reactive control systems is needed to prevent, forecast and take control actions against schedule deviations effectively.

3.5.1.2 Production control charts

This control tool is a matrix of tasks and locations representing the whole project status in a single chart. The x-axis represent the tasks and the y-axis the locations. Each cell of the matrix contains the status of the tasks happening in a determined location. This status is featured by colors and dates (Kenley & Seppänen, 2009a):

- Green indicates the location is finished.
- Blue indicates that the task is going on in a location on schedule as planned.
- Yellow indicates that the tasks in going delayed on in a location.
- Red indicates that a task should have started but is delayed.
- Other colors (partial colors) may be used to represent the interrupted locations.
- The numbers show the start and finish date for both planned and actual situations, or a percentage of the task accomplished.

With the LBMS it is possible to update automatically the chart based in the flowline and other project data when using the commercial solutions as VICO Office. In other planning methods as CPM, these charts are also used but they are normally set using excel or other spreadsheets which does not allow the automatic response to changes. The information gathered in this charts will feed the flowline forecast.



Figure 20 - Production control chart (VICO Software, 2013)

3.5.1.3 Flowline forecasts

The flowline forecasts include the representation of the planned, actual and forecast project progress. In a real project, there is an elevated amount of tasks so the change in the labor rate of a task can affect its subsequent tasks. This might bring the necessity to modify these posterior tasks to keep the overall project out of delays. Figure 21 shows the effect of the deviations for three different tasks (Structure, Windows 1 and Windows 2) where the workflow is in a critical situation, since the forecast show overlapping of tasks in the same location given by the alarm (noted as a dot).

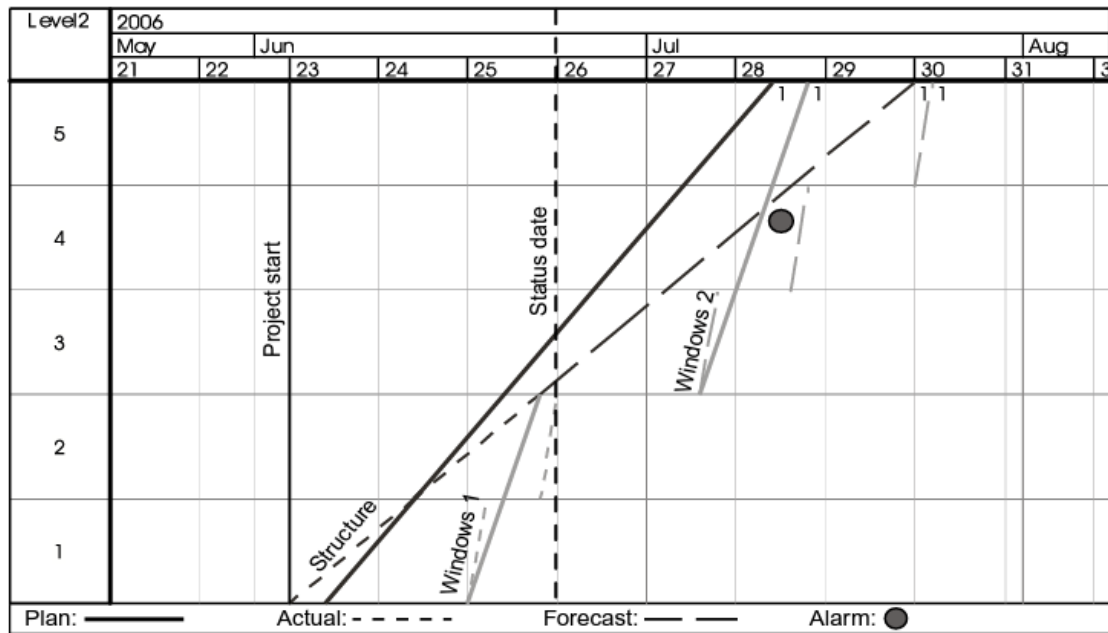


Figure 21- Tasks progress in a flowline using actual and forecast lines (Kenley & Seppänen, 2009a)

3.5.2 Flow continuity: from the lean perspective to the LBMS

A basic principle that has been set as one of the main focuses of this master thesis is the continuity of the workflow. The roots of this idea are settled in the lean construction philosophy. This flow is not unique of the project tasks when performed but is embed in all the elements of the project. The Lean Construction Institute has defined the *Lean Project Delivery System* (Figure 22) as a mechanism containing the five interconnected phases of a project (project definition, lean design, lean supply, lean assembly and product use) involving downstream all the actors of the planning process (Ballard, 2000). The objectives of this tool are to generate value in the process and to create reliable workflow relationships among the participants in the project.

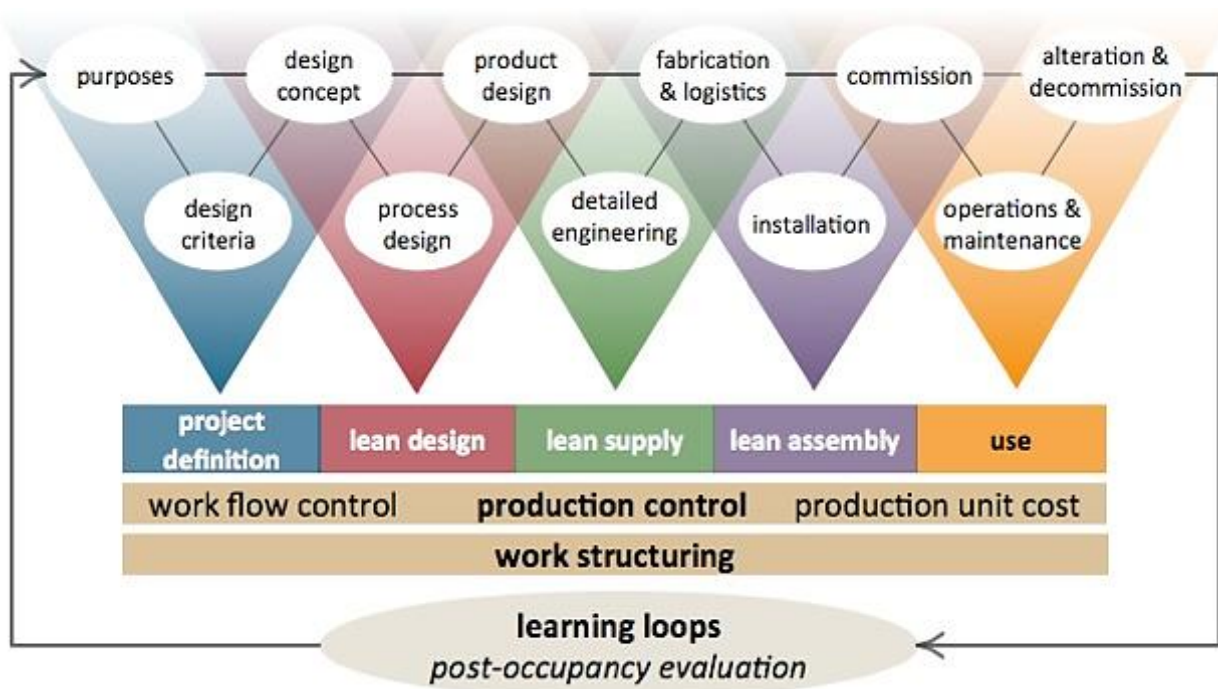


Figure 22- The Lean Project Delivery System (Ballard, 2000)

The objective in this thesis is to analyze the workflow continuity in a lower level, corresponding with the project tasks continuity and labor continuity. Thus, the lean aspects underneath the location-based planning methods are taken into consideration.

As seen before (see 3.4.4 *Resource loading and leveling*), allocating resources under a LBMS perspective is a part to set the prerequisites to ensure continuity, at least in the project resources. In addition, the possibility of setting workable backlog activities is another resource to be implemented to avoid stopping periods of the working crews, hence maintaining the ‘*takt*’ rhythm and the efficiency in terms of time usage.

In addition, when defining the project tasks, this can be establish in the most optimal way towards continuity of the flow or, on the other hand, in a discontinuous manner if the project constraints require it so. Hence, each task can be set to be (VICO Software, 2008):

- As early as possible: the task will start as early as possible in each location depending on its dependencies with the other tasks.

- Paced: the task will be set in a continuous way going through the different locations of the project where it is supposed to be performed, with no interruption for the resources.
- Forces as soon as possible and paced: the task will be performed continuously starting in the earliest possible date given its dependencies.

With the computational tools available, it is straightforward to define both the resources allocated to a task and its continuity features, resulting in a visual solution that will enable the user to optimize it in a relatively easy process.

3.6 VICO OFFICE

VICO Office is a set of technical tools developed in close relation with LBMS. The software itself provides integrated location-based planning, control and management solutions for construction projects (Kenley & Seppänen, 2009a).

VICO was established out of Graphisoft in 2007 with the aim of prioritizing the use of BIM (Building Information Modelling) in both progress planning and cost analysis of construction projects. The main goal of the technical solutions developed is to integrate the whole building process with a BIM model as starting point. This is very important especially for the contractors, which especially in USA have started to use these software solutions as a gradually more used common practice. However, VICO clients are not only located in USA but also all around the world. In Norway, the widespread process is increasing and there are several companies that have already implemented it in their activities. Skanska Norge AS is among the current VICO users (Blom, 2011).

VICO Office is one of the products released by VICO. It represents an integrated Virtual Construction environment. The software consists of a core module and a set of discipline-specific application modules. Each VICO Office application shares access to the same, integrated, project database, which ensures that a change in one of them will be reflected in the others. The user can go through the program modules with a highly interactive interface. The software links different areas related with planning and management of construction projects. This is achieved through different contextual levels, which can be sorted as Explore, Plan, Control and Manage levels (VICO Software, 2012).

The user is able to import a 3D model from different platforms (Revit, Tekla, ArchiCAD, etc.) to merge it with the project database where the rest of the project information is stored. This model acts as the basis for the software modules to establish the workflow. All the Office components are integrated in the same database to ensure data homogeneity. There are many functions grouped together according to the project planning phase in the different modules of the software. The modules included in the Office platform are Takeoff Manager, Cost Planner, Cost Explorer, Constructability

Manager, Layout Manager, LBS Manager, Schedule Planner, Production Controller, and 4D Manager. All of these modules can be reached and controlled from the VICO Office Client (VICO Software, 2012).

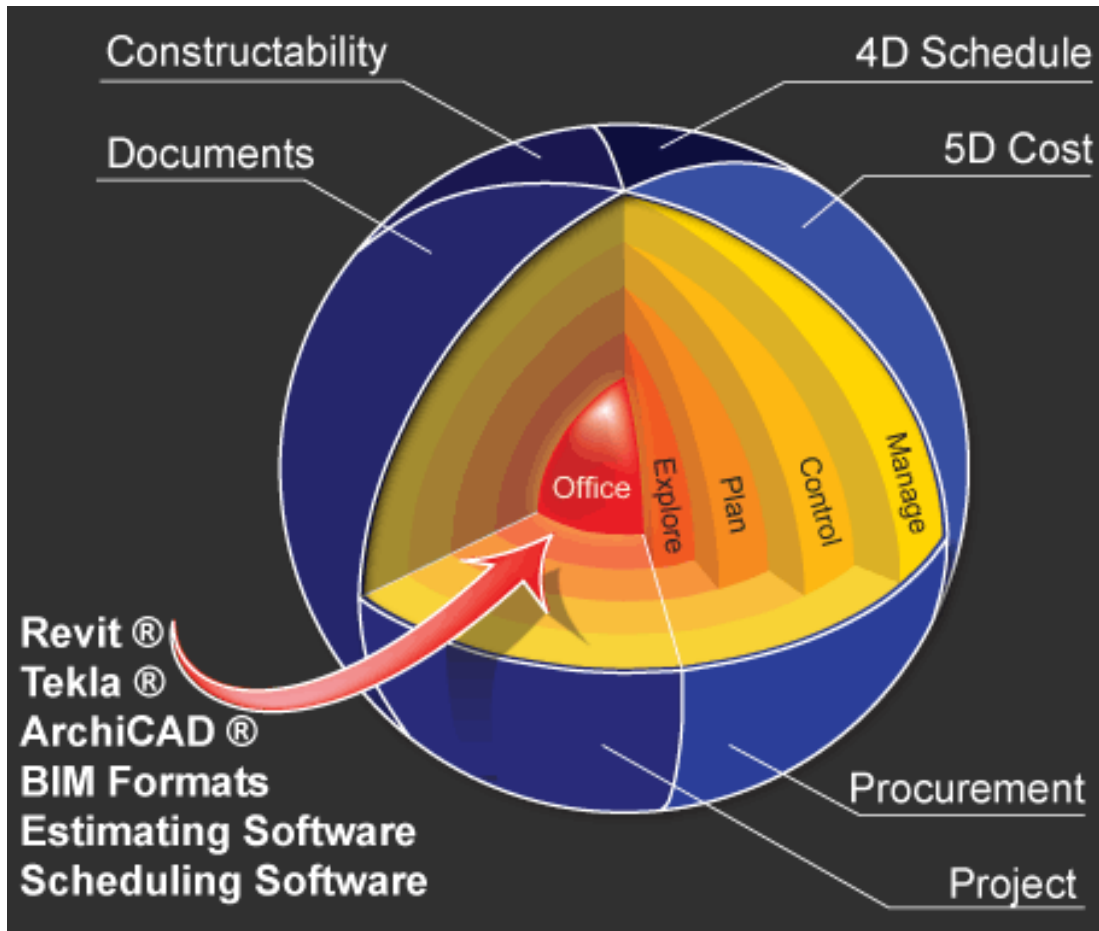


Figure 23 - VICO Office modules integrated in a 3D-4D-5D BIM workflow (VICO Software, 2012)

3.6.1 VICO workflow steps

The workflow in VICO Office can be modelled in 11 steps as defined in the next table:

STEP	MODULE	DESCRIPTION
1	VO Client	Project creation. Publish, augment, and compare 3D BIM models.
2	VO Constructability Manager	Detection of constructability issues. These are promoted to a RFI (request for information) and tracked through the project management data flow.
3	VO Layout Manager	Map all the identified constructability issues. Compare the original design to the as-built conditions and check for discrepancies. Identify coordination issues.
4	VO Takeoff Manager	Generate construction-caliber quantities.
5	VO Cost Planner	Estimation through iterations of the 5D estimate as the models' level of detail increases.
6	VO Cost Explorer	Project budget creation.
7	VO LBS Manager	Evaluation of the project and creation of the optimal combination of location systems, from the quantities generated as starting point.
8	VO Schedule Planner	Organize locations and find the optimal work sequence using flowline solutions.
9	VO 4D Manager	Evaluate what-if scenarios and determine the best solution.
10	VO Production Controller	Monitor and adjust crews as necessary when the project is on site.
11	VO Client	Create construction management report.

Table 4 - VICO workflow through its modules (VICO Software, 2012)

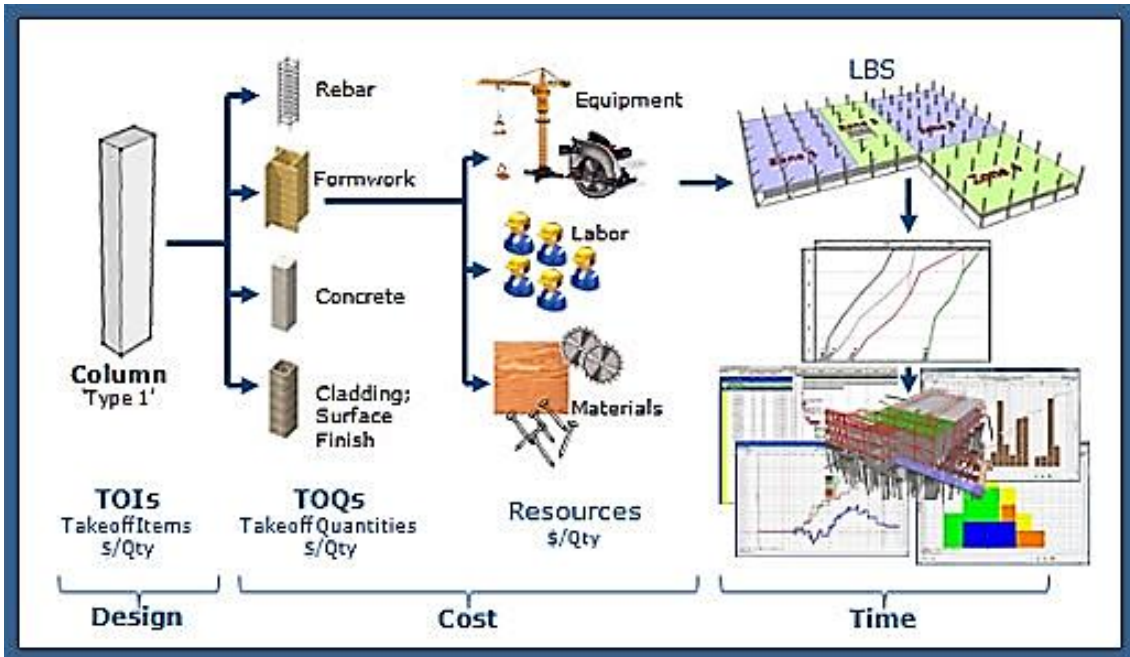


Figure 24 - 5D workflow (3D design + cost + time) (VICO Software, 2013)

The way in which VICO and its workflow are defined makes this solution the only one in the market which integrates 3D geometry, quantities, 4D schedule and 5D cost estimates. Consequently, for example, a modification in the 3D model entails a corresponding change in the other elements of the model (quantities, schedule and cost).

3.6.2 From 3D model to 5D

The VICO workflow sequence has been defined in 11 steps integrating the different modules that the software counts with. On continuation it will be described this process undertaken from the user perspective (VICO Software, 2010). Afterwards, it will be exemplified with the help of the case study included in this thesis.

1. First, when taking into consideration the physical characteristics of the project there may be two possibilities. The available *design data* is either available in 2D or 3D. In any case, it is necessary to determine whether there are changes to be made in the specifications of the project to create the model (in case of 2D data) or develop a construction model which includes also the means and methods to

- be used in the construction (in the case of 3D data). This can be done with BIM and requires good effort in coordination to map the project features properly.
2. The next step is the project take off with the estimation of its quantities (BoQ). In order to derivate an accurate bill of quantities it is necessary that the geometric information and requirements gathered in the previous point are as precise as possible. This will determine in a high degree the costs derived from the materials usage.
 3. Thirdly, the Location Breakdown Structure (LBS) takes place. This process has a great impact in the project management since locations are the unit of study, and its definition will determine, for instance, the impact in the materials delivery and procurement activities.
 4. Once the physical units of the project are set, it is time for cost estimating. VICO provides a 5D library with information about previous projects and historical data about material costs, tasks durations etc. which is the base for the cost derivations.
 5. The last step is to derive the flowline schedule based in the four previous points and using the 5D library data parameters.

There is no need to undertake this process from scratch every time a project starts. Due to the principles of standardization and repetition, in relation with the theory underneath LBMS, it is possible to use the mentioned 5D library available in the software. Furthermore, this library should be reused and enlarged after every project. Thus, the process can be seen from an iterative perspective enabling the user to apply their experience and historical information to optimize its planning efficiency.

4. CASE STUDY

4.1 COMPANY DESCRIPTION: Skanska Norge AS

The project under study in the next section is part of the Skanska Norge AS's portfolio. Skanska Norge is part of the Skanska group, one of the world's leader construction groups. This group originally started in Sweden and its main activity focuses in the development of commercial and residential projects with both public and private partnerships. The group counts with around 53.000 employees working in Europa, USA and South America. Its revenues were of 121,7 million SEK in 2010.

Skanska Norge is also a leading competitor in the construction business in Norway. It was established in 1906 (originally named Ing. F. Selmer) and counts with around 4.300 employees (including its partner companies). In 2012 it registered 13,4 million NOK in revenues (Skanska Norge AS, 2013).

4.2 CONTEXT DESCRIPTION

The project under study takes its name from its location in Schweigårdsgate 21-23. This location is in a very central neighborhood of Oslo, in the district of Bjørvika.

The project has ROM Eiendom AS as client, with OEC Consulting AS in the project management services and Skanska Norge AS as constructor. The architectural design has been developed by Lund+Slaatto Arkitekter. The construction process started in April 2011 and is planned to be finished in October 2013.

The assignment was awarded to Skanska as a turnkey project and once delivered it will be used as the new main offices for NSB (building 23) and Gjensidige Forsikring ASA (building 21). The project consist of two office buildings of eight floors connected by a bridge which will also hold a meeting room, and three basement floors common for both buildings. Between the two buildings, there will be a green open urban area.

The project counts with a total approximate area of 31.000 m². From this total space, Gjensidige will have 620 working places in a building of 16.200 m² and NSB will have 600 working places in a building of 15.000 m².

The construction works are developed normally from Monday to Friday from 7:00 to 19:00. In some cases, due to delays, when it is needed to work overtime Saturdays will be also used as working days with working hours from 7:00 to 16:00.

4.3 CASE DESCRIPTION

As part of the research process, it has been possible to visit the building site in Schweigårdsgate 21-23. This visit has been a great source of information both obtained through own observations and understanding, and through direct dialogue and explanations given by Lars Aasen about the planning systems and tools used in this project.



Figure 25 - Schweigårdsgate 21-23 once finished (Lund+Slaatto Arkitekter, 2013)

4.3.1 Site description and observations

Given a first view to the project and its characteristics it is noticeable the opportunity to establish a standardized pattern for working. This is due to its architectural design, which takes the different floors as systematic units of analysis, giving room for the implementation of activity repetition in the different project locations. This is a very important point for the study of this thesis, since the focus is on location-based planning methods where the physical project locations are the units of analysis. Even though the planning has not been directly undertaken from this perspective, it counts with all the elements needed to implement this approach, and it can be stated that is implemented in a certain way.

Taking the floors as location unit, their main feature is that these are diaphanous areas acting as working office spaces with some meeting rooms and small differences between each other's features. The basements are on the other hand different in their disposition, since they are a common space for both buildings 21 and 23, and the 5th floor it is also different since it is where the canteen and kitchen are located.

Given the amplitude of the working spaces, there are several crews performing different tasks simultaneously without much interference between each other. During the site visit, there were not sensation of being in a very crowded place and there was also a general impression of quite clean and tidy spaces, which may help avoiding disturbances for the workers. In addition, the atmosphere among the employees working in both the site and office is quite good, which may contribute to a health status of the relations between the subcontractors, giving a more opened mindset when planning and performing the different tasks.

According to the project manager (Lars Aasen), there is a path set for the crews to perform in each floor so they do not disturb each other. The crews also receive instructions about when to start and stop working in a determined area. This concept is set in relation with the concept of workflow as a 'train' established in lean construction (Skaret, 2012). Some common mistakes that lead to delays are to follow a wrong path in this flow, start the sequence in the wrong point or not follow the start-stop times given.

Other common source of delays is the design. Sometimes there are mistakes or unforeseen elements that cannot be finished as, for example, some wall corners which are not of the same characteristics as the rest and were not properly planned, or some other details that due to contradictions between design and safety measures need to be redesigned before they are correctly undertaken.

4.3.2 Backwards planning (Reverse planning)

Also known in Norwegian as *bakoverplanlegging*, this tool has been recently implemented in Skanska in relation with the lean construction principles, to ensure quality in the scheduling process. The aim is to establish the common practices related to lean construction in the company, given the actual differences between the different units within Skanska (Linge, 2012). Moreover, this tool is a very effective way of developing the so-called involving planning (*involverende planlegging* in Norwegian) where also the subcontractors are engaged with the project planning.

The main idea behind backwards planning is to plan from the final project date to the starting date. The final date of the project is considered a milestone to be achieved. Hence, the activities are set in the plan by those who are to perform them, giving their estimated time to do so and taking into account the preceding required activities to the actual execution. In this way are the subcontractors themselves who set their own performing times according to their experience and project constraints. Later on, the data collected in the paper chart will be translated into a document (generally MS Project document) with the aim of representing the project through a Gantt chart.

Normally the procedure entails a paper chart with a time scale, which can be hung in a wall where the different milestones and tasks are set with notes or post-its, in a visual way. In the case of Schweigårdsgate 21-23, the method was deployed at the beginning of the project in some intensive sessions with the participation of all the subcontractors and Skanska planners. The common practice is to keep it in a distended atmosphere which aims to reach the collaboration and openness levels needed to obtain a realistic final plan. The chart of this case study was developed in a room covering a big extension

of the walls, given the great number of involved activities and complexity of the project. A part of the chart (the one corresponding to the actual time and next months) is also hung in the canteen so everybody has access to it at any time. This is important, since planning itself does not ensure the accomplishment of the plan, but also acknowledgment and follow-up is needed.

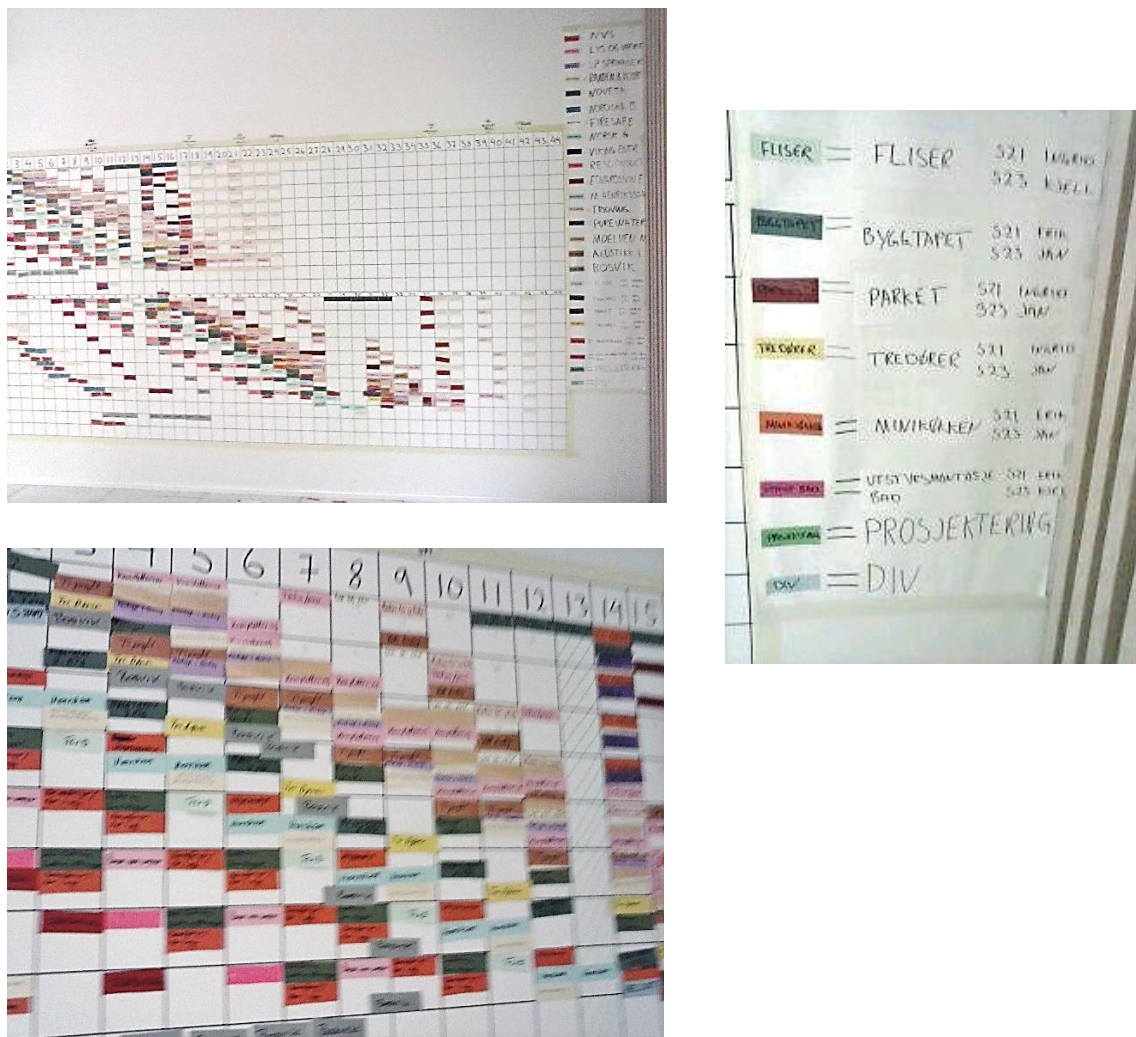


Figure 26 - Backwards planning charts (Schweigårdsgate 21-23 building site)

Among the advantages of this method is the transparency for all the users. It implies the involvement of all the subcontractors or any part who has to develop any task in the project. As a result, the different parts involved keep a more realistic perspective given the milestones set, a more transparent agenda and a better understanding of the whole project plan and tasks interrelations, since they are also the planners.

However, there are some challenges related to this method. It is essential to define clear milestones that will set the timeframe limits within the project. These functional milestones will be located between the starting and ending project dates, and they might be difficult to be identified. Set their correct timing is also important since the plan should ensure enough time between subsequent project phases for a correct performance and results. (Kalsaas et al., 2010)

4.3.3 General planning

After the Gantt charts and the entire project activities have been defined with the help of MS Project, there are some considerations related with the general planning of the project and its follow-up:

- The plan developed has to be acknowledged by the involved parts so activities are performed within the quality, time and costs established.
- It is noticeable that the relationship between subsequent activities follows a finish to start (F-S) relation. In the Gantt chart it is also visible that there are parallel activities being performed.
- To follow up the project progress it is needed to evaluate the percentage of each activity finished. These percentages should be updated in the document regularly to assess the situation of the project in terms of delays.
- The subcontractors are also involved in the follow up of the project and take part of the regular meetings to evaluate the project progress status. In these meetings the progress is followed up with the help of project plans both for the floors and façades, so if there are elements unfinished these can be accurately mapped and the causes for the delays determined, which will help to set the actions required to finish the task.

4.4 DATA GATHERING

4.4.1 Data gathering tools: interview, questionnaires, project database, plans, public information

Choosing a real project as a basis for the case study has been a great source of data, but as a previous step to its analysis itself, it is needed to select the tools and approach to gather such information.

Due to the collaboration with people involved in Skanska Norge AS and particularly with the project under study here, it has been a relatively simple process to access relevant and reliable data.

The general framework and conditions of the project have been found on the internet, mainly in websites related with the project client or other parts involved as Rom Eiendom AS or Lund+Slaatto Arkitekter. Having access to the project database has been key to get to see the plans and other technical documents of great importance. However, the most important sources have been the ones established by direct contact with the project manager Lars Aasen and the subcontractors. Hence, through interviews, questionnaires and dialogue a great part of this study data has been collected (see *Appendix C: Case Study*).

The initial idea was to perform structured interviews to the project manager and the subcontractors, but due to the number of subcontractors involved and the time available to perform those, it was decided to use an online questionnaire which aims to gather the corresponding information in a more efficient way.

4.5 USE OF VICO OFFICE

4.5.1 Limitations and assumptions

Given the scope of this master thesis and the time available to develop it, there are certain limitations to have into account when obtaining the expected results, and furthermore when analyzing them. These constraints have been also taken into account

when it comes to discuss the outcomes found, and especially at the moment of inferring conclusions related. Thus, a critical analysis must be kept along the process without forgetting that the aim is to represent the behavior of the project under a different management perspective, but thinking that this is ultimately done from a theoretical point of view here, so the real circumstances could lead to different results.

VICO as a software solution provides a great variety of tools for project planning, but here the main points under consideration will be the Location Breakdown Structure (LBS) and the scheduling. Therefore, the module to be used will be only the Schedule Planner. In a real situation where the planning of a project is to be undertaken starting from the geometry, to calculate the quantities and related costs, the approach would be different. In this case, all the modules should be used according to the workflow previously explained (see 3.6 *VICO OFFICE*). Here, it is needed to design a 3D module that would be linked to the project and would act as reference point for all the modules once imported from the corresponding CAD tool to VICO.

During the implementation of the software in this thesis, a problem arisen related with the interconnection of the modules given the need to use only one. The program itself claimed to have a model in order to be able to establish the locations as main point to start using the Schedule Planner. Since the focus here was not the design, it was decided to reach and use the module outside the VICO Office framework, thus, if accessed from the program archives directly (using the route *C:\Program Files\Vico Software\Vico Office (x64)\Wow64\VS_Control.exe*) it is possible to use exclusively that module. This gives the possibility of only focus in the schedule but it makes impossible to link the schedule to a VICO project. Hence, it is remarkable that this approach should only be taken under these circumstances and not when undertaking the planning of a project in a real scenario where all the variables and parameters should be taken into account.

The flowline schedule will be developed using the Schedule Planner module. As starting point when it comes to the analysis of the tasks to be performed, the Gantt chart developed from the backwards planning will be used. As this chart counts with 1894 lines (one line per activity) counting all the tasks and subtasks for all the project locations, its study will be reduced to just one of the buildings of the project (building

23). The scope of the study will be also reduced in the sense that either the basement floors, the connecting bridge between the buildings or the surrounding areas will be analyzed. The tasks that will be included in the optimization are those related with the structural works (Råbygg S23) which in total sum 43 tasks

Related with the optimization of the project schedule is also the resource loading, that will be studied mainly from a qualitative point of view, where the information will be founded in the opinion and conceptual terms of the project leader and subcontractors. In this point, the interviews and questionnaire responses will be the main data source.

4.5.2 LBS - Location Breakdown Structure

In this point of the study the LBS will be considered, first according to the actual plan that the project is following and then finding the optimal LBS to reach the pursued continuous workflow. According to the limitations established previously, not all the tasks will be considered, but only the 43 tasks related with the structural works of the building 23. In the initial Gantt chart, these tasks can be sorted in the next locations:

- Eight floors
- Façades south, west, east and north, grouped in floors from 1st to 4th, and from 5th to 8th
- Roof

According with the information gathered during the visit to the Project and the interview with Lars Aasen, it should exist an established path for the workflow to follow by the crews working in each project location. During the review of the documents in the project database, any specific document was found related to this. In any case, the crews are supposed to follow a determined pattern when moving within a location. A possible pattern that this path could follow, given the accesses to the different floors through stairs and external elevators, is the next one:

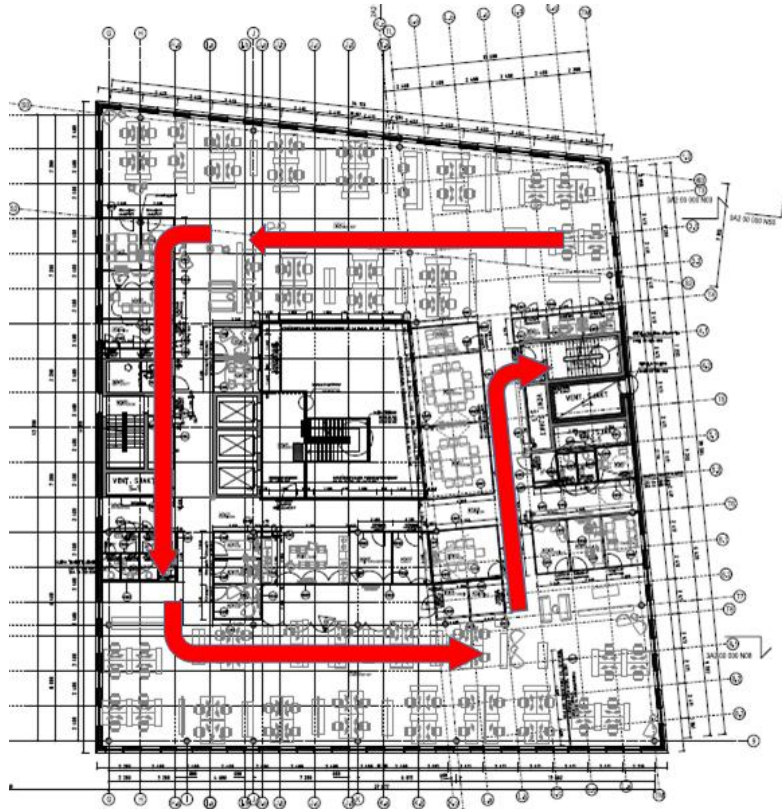


Figure 27 - Suggested working path to follow in each floor

4.5.3 Flowline scheduling

The initial point to develop the schedule object of optimization will be taking the data found in the Gantt chart corresponding to the chosen tasks, to transfer it into a flowline schedule. In the Gantt chart the information is given for each activity within each task (see *Table 5*). This information contains:

- Identification number
- Work Breakdown Structure indicating to which working group the task belongs
- Duration
- Start date
- Finish date
- Predecessors
- Subcontractor

The first challenge will be sorting the activities that are repeated in different locations, and which will constitute a task. An excel spreadsheet has been used for this matter and also to keep track of the tasks already introduced in the schedule planner (see *Table 5* and *Appendix C: Case Study*).

Once it is clear which tasks are going to be studied and in which locations do they take place, it is possible to put them into the Schedule Planner in VICO. The result will be a schedule that will be analyzed in the next point together with the rest of the project data to reach the best solution from the theoretical perspective introduced in the background of this master thesis.

4.6 ANALYSIS OF THE DATA

4.6.1 Interview and questionnaires data

Both the interview taken with Lars Aasen and the questionnaires that some subcontractors filled out are aimed to gather the same conceptual information. Their form of obtaining it differ due to this thesis scope and limitations. It is remarkable that the number of responses when it comes to the subcontractors' questionnaire is quite low and a great part of those where Skanska employees. Only 21 people out of more than 40 involved company representatives reached answered it. Therefore, the answers will be analyzed from a qualitative point of view given the chosen approach described in the methodology (see *2. Methodology*) and given that the limited size of the sample is not suitable for statistical studies. On continuation, the answers gathered will be studied according to their belonging to workflow or resourcing concepts. (see *Appendix C: Case Study*)

4.6.1.1 WORKFLOW

A thing that has been clear after gathering information about workflow understanding is a lack of consistency in the perception of this concept. When it comes to the definition of what workflow is, very few associated it with continuity of work, task repetition or standardization, and only one mentioned

the term lean construction. Furthermore, some answers were completely misleading from the real concept and some were not even able to answer the question. However, at least during the interview the definition given was a correct one, even considering the activities sequence along the project location as the 'train' movement concept previously explained.

Besides the proper specific training some companies might offer to their employees, it seems that it is still not very common to be trained about the lean philosophy in construction. Therefore, it is expected that not everybody is familiar with its principles and practices. The reality is, on the other hand, that employees with experience use the lean principles without knowing they belong to this theory.

When it comes to the practice, not all the activities are planned continuously, so it is basically impossible to reach a continuous workflow if it was not planned initially. Thus, the results in both performance and schedule progress might be jeopardized. However, it is remarkable that some answered that having a non-continuous planned work was contributing positively to their performance. But to understand this nuance it would be needed an in-depth analysis of the kind of activities this workflow relates to.

Complexity in a project like this is a basic characteristic and is defined through the activities conforming the project, its context, its environment and their interrelations as a system (Narayanan et al., 1993). An increasing level of complexity demands a higher level of coordination, which in this case the majority of the answers agreed upon. Coordination, among other things, should seek for the correct interaction between the actors performing the tasks, given the high level of colliding activities in the same working areas. Given the geometry of the building, the areas where this happens are supposed to be big enough to avoid excessive interaction between working crews, but their size is not sufficient according to the questionnaire answers. In addition, since there are many different subcontractors involved, the coordination should be established since an early stage of the planning, considering all the parts and

elements involved and making those parts of the planning process as well. Those who reported a late involvement in the planning and coordination processes were those who acknowledge a high potential of improvement in the project management in general, from logistics to HSE and other related elements.

In general, the gathered answers reflect the very different levels working in this particular project, regarding knowledge basis terms. Therefore, the approaches to a healthy and efficient workflow are very different, which might create differences within the project results, and have effects in the progress and performance of the different activities. However, in practice is noticeable that some experienced employees might be putting into practice until some extent the right principles without acknowledging it.

4.6.1.2 RESOURCES LOADING

When it comes to resource loading there are some issues that are remarkable, considering the practices that have been used according to the general information collected about the project. Backwards planning with the subcontractors involved was undertaken, which should be the basis together with their own previous experience to allocate resources for the given tasks. However, it seems that a great part of the answers do not agree in having the optimal crew design to perform such tasks. Moreover, many of them are relying in working hours out of the established schedule to finish the tasks on time.

Many also reported that there are different crews working in different tasks in the same areas simultaneously which affects negatively their performance and the time plan, producing delays. This, together with the fact previously stated about the optimal crew design is translated in overtime work, which is negative for the workers performance if it becomes a regular practice.

Collaboration with Skanska has not been that active in this matter, but due to the low number of responses it might happen that other subcontractors have had further collaboration here. Anyhow, it is part of the involving planning that implies the use of backwards planning in this case, so at least the subcontractors

should acknowledge their own working capacity according to previous experience, and evaluate with Skanska realistically the number of resources needed given other constraints as time, space or quality. Even though this is how theoretically should have been done, some answers gathered agreed that the allocation was not done realistically according to the labor rates, therefore influencing their performance and probably introducing another prerequisite for not having an optimal crew design, and having to work overtime.

Another concept that was pointed out is the need to reach decisions regarding planning and resource loading before the actual production starts. Otherwise, there might be negative consequences regarding estimated time and costs.

4.6.2 Gantt diagram data

As explained previously in the literature review, Gantt diagrams have been the common practice when it comes to visual representation of project planning in the last years. In the case of this project, it has been also a main tool used especially to follow up the project and see the status of the tasks, delays etc. Due to the complexity level of such project, it might be questionable how easy and convenient is this method. In particular, for the tasks under consideration in this case study (structural works in the building 23 considering eight floors, the roof and the façades) this means to handle 210 lines in the diagram, which represents a quite big amount of data and if printed, it takes around 10 A4 sides.

In the case of considering the whole project, the amount of lines reaches 1895. Therefore, handling all the tasks' information in the same document becomes an exhausting process. Thinking towards the users of this document, it is easy to miss information when it comes to the updating of the document, since going through its totality requires a long time and this makes it inefficient. Reading through the document might not be clear either, since each task is represented for each location in which it takes place, so it is not clear to visualize the parallelism of tasks in the same working areas, or the transition between these ones.

Further in this document, it will be argued the improvement flowline scheduling represents towards the user needs using the chart as a planning and controlling tool.

4.6.3 Flowline schedule data prior to optimization

As explained above, the 210 lines under consideration for the optimization problem were taken from the MS Project document to transfer their information to the Schedule Planner. Firstly, the tasks were collected in a spreadsheet, grouped by the kind of task, and considered the locations in which they were taking place. This gives a result of 43 tasks, which probably could be reduced if the planning considered continuity of tasks along locations as it will be argued in the discussion further down. (see also *Appendix C: Case Study*)

Floors	1	Roof	25
	2 (2-1 to 2-8)		26
	3 (3-1 to 3-8)		27
	4 (4-1 to 4-8)		28
	5 (5-1 to 5-8)		29
	6 (6-1 to 6-8)		30
	7 (7-1 to 7-8)		31
	8 (8-1 to 8-8)		32
	9 (9-1 to 9-8)		33
	10 (10-1 to 10-8)		34
	11 (11-1 to 11-8)		35
	12 (12-1 to 12-8)		36
	13 (13-1 to 13-8)		37
	14 (14-1 to 14-8)		38
	15 (15-1 to 15-8)		39
	16 (16-1 to 16-8)		40
Façades	24 (24-1 to 24-2)	41	
	17 (17-1 to 17-8)	42	
	18 (18-1 to 18-8)	43	
	19 (19-1 to 19-8)		
	20 (20-1 to 20-8)		
	21 (21-1 to 21-8)		
	22 (22-1 to 22-8)		
23 (23-1 to 23-8)			

Table 5 - Tasks considered in the case study

When introducing the tasks information in VICO the next considerations have been taken:

- Since the information from the Gantt chart is given for each task in each location (as locations are considered in the planning with MS Project in this case), these have been introduced as split tasks. For example, the task 2-1 correspond to the task number 2 happening in the first floor.
- The dependencies between tasks (and within tasks) have been established according to the previous point, taking into consideration that the information available is given for split tasks.
- Since in the Gantt chart available there is not information about the staffing and the number of crews performing each task, it is assumed that there will be one crew per task initially. In the posterior process of optimization, the production rates in which the tasks are performed will be modified due to the alignment of the tasks, which means that the amount of resources used will be different.

Once these tasks have been introduced in VICO the result is a flowline schedule where the next points are noticeable (see *Appendix C: Case Study*):

- There is not much continuity within the tasks.
- Some tasks happen simultaneously in different locations.
- There is a lack of alignment between different tasks, which suggests that the working rhythms are very different from task to task.
- There are different tasks happening simultaneously in the same areas (those areas are supposed to be big enough, but is difficult to track the position of the tasks with this level of detail in the LBS). Some activities even have same starting and finishing date (in some cases 3 or 4 activities happen simultaneously).
- There are lack of buffers between some activities.
- The use of the space and time is not optimal in many cases.

4.7 OPTIMIZATION OF THE FLOWLINE SCHEDULE

Optimizing a problem pursuing an ideal solution is a great task itself and depends on many different parameters. To reach the optimal solution requires taking all of those parameters into account, which would require in this case the use of all the information regarding the project, its context and singularities. Consequently, these should be treated under a very wide perspective maximizing or minimizing each value for each parameter, and considering the interdependencies between all the involved variables.

Following the scope and limitations of the problem given here, a set of optimization criteria must be defined. These criteria seek to be aligned with the purpose of this master thesis and the goals set through the research questions.

4.7.1 Optimization Criteria

1. Task production should be aligned in each set of locations (a set of locations is defined here as the second level of the LBS hierarchy), considering these as the floors, the roof and the façades.
2. Tasks should be continuous.
3. The dependencies between the first task of a set of locations and the next one should be kept if possible.
4. The tasks should start on Monday if possible.
5. The presence of the subcontractors in the building site should be continuous, avoiding inactive periods of time.

These principles are listed as their priority towards the optimization. Thus, it would be preferable that tasks are undertaken continuously than the subcontractors' presence is uninterrupted. In practice, these principles have been followed over the graphical solution given by the original project data (data from the Gantt diagram) in VICO Schedule Planner to obtain the optimal solution.

SUBCONTRACTOR ID	SUBCONTRACTOR NAME	TASK	SEQUENCE
HT	Hesselbergtak AS	1, 26, 33	F, R, R
CON	Contiga AS	2, 28	F, R
FS ISO	Firesafe AS	3, 20	F, FA
NG	Norsk Gjenvinning AS	4, 30	F, R
EV	Viking Entreprenør AS	5	F
SPS	SP Sprinkler AS	7	F
LV	Lys og Varme AS	8, 9, 10, 41	F, F, F, R
NVS	NVS AS	6, 11, 12, 31, 39	F, F, F, R, R
RH	Randem & Hübert AS	13, 15, 38, 40	F, F, R, R
PW	The Pure Water Company AS	14	F
NB	Nordiska Byggporten AS	16	F
TE	Takelementer AS	17, 25	FA, R
SN	Skanska	18, 32	FA, R
EMV	EMV Construction AS	19	FA
NSM	Naturstein Montering AS	21	FA
VS		22, 42	FA, R
BN		23, 37	FA, R
BV	Bosvik AS	24, 34, 36	F, R, R
MP		27, 35	R, R
NC	Noracon AS	29, 43	R, R

Where F=floor, FA=façade and R=roof

Note: There are three companies registered in the project Gantt chart (VS, BN and MP) which do not appear in the *Møttereferat dokumentet*. Therefore, only their ID will be used.

Table 6 - Relation between subcontractors, tasks and tasks sequence in the project

4.7.2 Subcontractor and task relationship

Besides considering the initial flowline schedule, there has been other sorting in the information regarding the subcontractors and the sequence they were following initially in the project plan (see *Table 6*). Firstly, tasks have been grouped according to the subcontractors undertaking them. This makes clearer how many different companies are involved and which their assignments are. Secondly, and for each of the subcontractors, the sequence of the tasks they had to perform was determined. For example, Contiga AS has to perform the tasks nr. 2 and 28, which happen in the floors and roof, respectively. For this matter, the *Table 6* has been used.

4.7.3 New location hierarchy

A significant difference is made towards the optimization problem. In order to implement the concept of the ‘train’ moving along the project (see *3.4.4 Resource loading and leveling* and *3.5.2 Flow continuity*) a change in the location breakdown structure was needed. Indeed, it required to lower the level of detail introducing a third level in the location hierarchy of the floors from one to eight and the roof. However, the façades remain with the same location division. Hence, the new level introduces three sub locations for each of the second level mentioned:

1. Project
2. Floors (1-8), Façades and Roof
3. Sub locations 1, 2 and 3, for floors and roof only (see *Figure 28*)



Figure 28 - New LBS within the floors and roof with suggested path to follow

Once the relation between tasks, subcontractors and location groups is clear, optimization of the flowline schedule can be done. Given the initial schedule with the problems previously described, the next steps would be:

- Combine the activities into tasks. Initially, activities were introduced with their own starting and finishing dates for each location (with only two hierarchical levels).
- Force task continuity (paced tasks).
- Align the tasks production putting them parallel to each other.
- Order the tasks logically, considering the dependencies given in the Gantt diagram. At least the dependencies concerning the start of the first task of the second level in the LBS have been considered. Thus, for instance the relationship between the last task happening in the floors (nr. 16) and the first task happening in the façades (nr. 19) has been kept.
- Use a reasonable buffer between tasks to avoid task collisions in the same locations.

- Try to keep the continuity of the subcontractors on site given the information gathered in Table 6.

The result is a flowline schedule (see *Appendix C: Case Study*) with a clearer distribution of the tasks over the locations, finishing the same amount of work using nine working days less than the original schedule. The main characteristics of this new plan are:

- Task are continuous along the project locations.
- Visually it is easier to follow up for a given date where the progress of the different activities happening should be.
- Production is aligned, keeping a determined working rhythm.
- There are no tasks colliding in any project location.
- There is at least one day of buffer for the tasks to be finished without interfering the subsequent task.
- At least for the floors and roof, most of the tasks start on a Monday, which according to the project manager experience is needed to ease the tasks prerequisites (procurement tasks).

5. DISCUSSION

5.1 FLOWLINE SCHEDULE vs. GANTT CHART

When dealing with a construction project, where complexity and uncertainty levels are already high, it is necessary to find a scheduling method that all the parts involved can easily and intuitively understand and follow without any issue. Previously in this thesis have been given reasons to believe that the traditional methods as CPM or PERT are not appropriate and a further analysis of the project is needed, including its geometric characteristics, bill of quantities, costs, resources and timing for its activities. Therefore, the new perspective given by the location-based management methods is preferred.

After considering the literature studied and using both flowline and Gantt representations for the new and traditional methods respectively, there are some points worth to mention for their comparison. Firstly, efficiency when it comes to the information contained varies from one chart to the other. Not only in physical space, but also in the facility for understanding what the graphics represent. A Gantt chart requires around five more times of space (in paper sheets) than a flowline chart to represent the same tasks (for the case study used). Nevertheless, using flowline schedules is not just easier because it can be seen in an only glance; it is also more intuitive for the user, even if his experience in the topic is limited. If the user knows the geometry of the building it is easy to understand how the tasks should progress by seeing the lines that compound the flowline schedule. The slope of those lines gives an idea of how the work rates should be, meaning the speed that the working crews should have when performing their tasks in the different locations.

When it comes to monitoring and control, it is again easier to use a flowline schedule. As mentioned above, the introduction of the actual progress rates in VICO allows the software to make forecasts of the activities' evolution which, in addition, can be represented simultaneously in the same chart. This allows the user to have a clearer understanding of when the tasks are likely to be accomplished for a determined

location, so it will be also easier to decide if counteractions are needed to avoid or fix the deviations from the plan. The interrelation between the five dimensions present through the different modules in VICO, makes also an easier process for the user to have all the information embed in a unique database, knowing that a variation in one of the dimensions will be reflected automatically in the others.

Regarding resource loading, the approach of the traditional planning with logical networks differs from the one used in VICO. When managing resources in flowline schedules, a resource registry will be used. The aim here is to track the availability of the resources so the tasks will be delayed until the required units are available (VICO Software, 2008). Another possibility to cope with the resources availability is to decrease the working rate in case the task can be performed with a lower number of resources during a longer time. So, according to this perspective, and on the contrary as in CPM or PERT, there is not assumption of total availability of the resources, which is not a realistic basis in most of the cases. A subcontractor will be normally involved in many projects simultaneously, having its resources therefore divided among them, which most likely will result in lack of availability in certain periods of the required resources.

5.2 USE OF LOCATION-BASED MANAGEMENT SYSTEMS

Even though LBMS have not been used consciously in the project under consideration in the case study, some of its principles have been considered and it is clear that the working methodologies are gradually changing, at least in Skanska Norge.

The main consideration needed as a prerequisite to implement LBMS is the use of the locations as standardized units for planning and control. In the project Schweigårdsgate 21-23, there was a realization of the potential inherent to the activities repetition. Therefore, its planning considered its geometrically similar units to create a standard unit, the floor. This is an advantage when it comes to planning since it does not require to evaluate each activity singularly for each element of the project, saving time and effort for the planners. Also given the repetition of the tasks from one unit to the next

one, flaws could be detected during monitoring and try to be solved for subsequent units. This would require an efficient use of change management, which has not been a focus of this master thesis, but in any case is necessary to be considered in a real project scenario.

According to the interview and questionnaires data, the practices in the construction industry are in a transformation process, at least as reflected in this case study. At this moment they are evolving from the traditional planning methodologies to the new methods in connection with the principles embed in lean construction. The companies of this sector are realizing that to continue being competitive in the market they need to adapt themselves to the new client requirements not just according to the classical time, cost and quality needs, but also considering the value creation a project should represent (Koskela, 1992). This value is not considered just as the fulfilment of the client expectations and needs, but as for all the stakeholders considering as well the final users and all the actors involved in the project planning and execution.

The transformation of the construction industry is coming in different ways and with the help of different tools. Companies are training their employees in some cases, introducing them to the new tools and better practices, as to the theories underneath. In other cases, experience has lead the employees to use some of the lean and location-based principles without knowing they belong to these philosophies since common sense focused in the efficient use of time and resources lead to those. In any case, the information of the case study reflected a great variety of understanding of the basic concepts related to workflow and resource loading. This should be improved in for future projects since the lack of knowledge consistency can be the source of problems such as communication between the parts, which may affect the planning, controlling or coordination of the project itself. In some cases, for special projects as St. Olavs Hospital in Trondheim (Midt-Norge Helsebygg, 2012) specific training about lean construction (trimmet bygging) was delivered to the employees so everybody could start from the same understanding basis. This, of course requires investing both time and

money, but it could be beneficial for the project outcome, so it should be at least considered.

If such training about LBMS was undertaken it would be much easier to implement continuous planning of the tasks along the project locations, and the subcontractors should be more aware of their role in the planning, acknowledging their own working capacity and the plan to be followed itself.

According with the data gathered in the case study, and even though there is an ongoing evolution of the construction business, there is still a long path to go. In other words, the problems that the parts involved in the case identified claim for the implementation of LBMS. Considering task continuity, LBMS would represent an improvement in the workflow through the project. This would ease coordination, reducing collisions and conflicts between activities and resources. It would also help to foresee the progress of the project and its deviations from the plan, which would ease the decision making when it comes to actions against schedule deviations. As for resourcing, LBMS makes easier to determine the desired working rates. Therefore, according with the labor rates, project quantities, time and spaces available it would be easier to set the number of resources needed.

5.3 RESOURCING METHODOLOGY

Resourcing, as done in the case study, could be classified among the traditional methods. In this case, a combination of heuristics and deterministic approaches is the root to allocate resources. Given that the subcontractors have used their previous experiences in this matter, it could be stated that they have used their own logical rules to establish the resources' availability in the project according to their own portfolio and historical data. As far as the information about resourcing has been limited, apparently uncertainty has not been taken into consideration directly. Thus, if the tasks duration have been considered an average fixed value based on historical data, the approach is deterministic.

In accordance with the data gathered, labor continuity in the workflow has not been a regard. Therefore, since this is a basic pillar of LBMS and its resourcing perspective, the process followed is far from being under this methodology. Since the labor flow is not under consideration, there is not room for the deployment of the '*takt*' concept of finding an optimal working rhythm.

Even though a certain LBS has been followed, the basic planning concept used its supported by the activities as unit of analysis. The locations in relation with the resources working on them have been disregarded when planning. The consequence is clear according to the questionnaire answers: activities undertaken by different crews collide. These collisions are negative for the performance and schedule, and a LBMS perspective in this aspect would improve it. Thus, if a proper LBS is done and a proper amount of resources is allocated according with the characteristics of the schedule tasks, quantities and determined resource consumption rates, a proper workflow could be established avoiding the mentioned problems.

An advantage of this work and labor flows towards the resources themselves would be a more efficient use of the time when working, which could prevent delays and working extra hours.

A main aspect to look upon when converting the resourcing approach is the concept underlying in the third level of the layered logic applied in LBMS. This is the main difference between the logical network methods and the LBMS and it represents the resource leveling of the activities within a task. This should be considered when the working rates change from one location to another or in case the locations' characteristics differ so the resources allocated should be adapted to work in a different space.

Finally, is worth to mention a method that has been used in the project and is basic to reach an efficient resource planning combining all the parts involved. This is the backwards planning. It is important for this matter since a good relation of the planners based in mutual trust and transparency will most likely result in a more realistic approach for resourcing. If subcontractors feel comfortable in the way tasks are demanded to them, their response in their estimations and requirements towards the

others will be more reliable. The result would be therefore more beneficial for the final project outcome.

5.4 INVOLVEMENT IN THE PROJECT

It is clear that a main concern for Skanska has been to keep high rates of involvement of the subcontractors. The objective is simple, set common goals for all the parts. Using backwards planning provides a great tool to achieve this. It is of simple deployment given that the subcontractors want to take part of it. If so, it becomes not just a simple tool for planning, but it also represents a way to develop the team-building spirit. This might seem a bit irrelevant in an industry where pragmatism is a key issue. Indeed, a well formed team (in this case initially by involving the subcontractors as main planners) results in more transparency in communication avoiding for example hidden agendas, and a coherent plan to undertake the project with a common perspective regarding time, costs, quality and value creation (Elvenes, 2011).

Such team is more likely not just to put more effort but also have a higher responsibility feeling considering seriously their performance and how this may affect the others' performances as well. These characteristics should facilitate the progress of the project actions as planned, which is also positive since it might trigger higher motivation of all the parts towards better outcomes. In some cases, rewards or bonuses could be used as incentives, but this should be taken into closer discussion for each case.

In the case study it has been shown that there have been involvement of the subcontractors in many cases or at least Skanska has tried to do so. Involvement in this case came also with certain freedom for them, as they were not forced to use established methods or labor rates. On the contrary, subcontractors have used their experience in previous projects to set their own resource usage according to their possibilities and requirements established by Skanska. On the other hand, many claimed a higher need for coordination in the project activities, which may be reflecting a lack of integration of the different parts in the project.

In addition to this process of involvement it is needed to make the parts acknowledge the plan and their position in it so they can follow and accomplish it. This is related with the mentioned lack of cohesion in the knowledge basis (see 5.2 *Use of LBMS*). Involvement requires understanding and an active role from those who are intended to be part of the team. Otherwise, it is difficult to align the different objectives into common goals for the project endeavor.

5.5 COMPLEXITY AND UNCERTAINTY IN VICO

The use of VICO in a real scenario has as starting point the definition of a 3D model with the project geometry. This model establishes the basis for the LBS, the bill of quantities and the rest of elements integrating the 4th and 5th dimensions of cost and time.

Traditionally, construction projects have been characterized by highly complex and uncertain endeavors related with the singular character of each project. The elevated number of components, stakeholders and requirements to be fulfilled by a project increase complexity resulting in higher uncertainty of the outcomes. This uncertainty is related to both opportunity and risk depending on the positive or negative nature of the outcomes, respectively. These characteristics are embed in all the project phases from design to completion, but their levels may be reduced as the information levels increase with the time.

When it comes to the project physical definition of its geometry, there is a great evolution from the first conceptual drafts to the final solution agreed. Indeed, the final solution may be reached in an already advanced phase of the construction. Using BIM as VICO does to integrate the project 3D model for planning and estimating other aspects of the project, requires to assume that the model used is already the final solution. This is probably far to be true in most of the real scenarios. Therefore, it seems to be a certain reluctance to implement BIM more actively as a tool for construction design and planning.

The difference from the initial to the final solutions in a construction project are large, and the changes may be happening until a late point of the construction itself. On the other hand, planning using BIM requires the use of 3D models with a high level of detail. If such plans are likely to be modified it requires a long time to adapt again to such level of detail. In this case, many users may question why to go through so detailed plans when using BIM if they are going to be changed. However, if the detail level is not enough it is dubious that the other modules in VICO will get to a realistic estimation.

As VICO relays theoretically in the LBMS, which is itself related to the lean principle of decreasing the variability towards standardized processes, it can be argued that the singularity inherent to construction projects keeps them away to be the ideal kind of projects for this planning perspective. Thus, it can be explained why the deployment of solutions as VICO or other BIM tools has not yet gotten to a common practice in the sector.

5.6 COMPARING PRE- AND POST-OPTIMIZED SOLUTIONS

Optimizing a part of the schedule for the case study has been challenging but also a good way to realize about the advantages of using flowline scheduling. After analyzing the data, it is possible to compare two different solutions, both already under the same flowline format. Visually it is clear which solution any planner would most likely choose if they had to use it to deploy and follow up the schedule. The post-optimized solution presents the characteristics described above (see *4.7 OPTIMIZATION OF THE FLOWLINE SCHEDULE* and *Appendix C: Case Study*) and it could also be said that it is a more 'esthetical' solution which transmits information in a very clear, tidy and intuitive way. After having processed both pre and post-optimized solutions, is much easier to work with the second one in terms of efficiency since its reading is straightforward for any user with a minimal understanding of the LBS and LBMS.

Going from the Gantt chart to the theoretically optimal solution according to the thesis limitations and established criteria has not been simple, and probably this is because it

requires understanding of both traditional and new planning methods, as well as the transition from the activity to the location as a unit of study. Therefore, this task would have been simpler if the LBMS perspective would have been adopted from the beginning of the planning. If considering the project plan initially to be performed with an established workflow in its tasks and resources usage, it is easier to establish a continuous implementation of those. However, if this is not considered, there is high probability that the activities will be undertaken in a non-continuous sequence with multiple starts-stops, which may be translated into poorer performance or delays in the schedule due to the changes in the working rates.

A project like this, with a high number of subcontractors or parts involved, requires coordination between its tasks. In the case that those tasks are aligned following the established pattern of locations and a determined rhythm, such coordination may be eased. Thus, this represents an advantage not only to follow up the progress of those tasks along the project, but also to monitor the actual progress against the planned one and take actions on time to keep the progress rates. Preventing tasks' delays or solving them is a key issue in coordination so subsequent tasks are not affected. A matter of fact is that even the perfect plan will never happen 100% as planned, so this coordination and follow up is essential to ensure the achievement of the goals established at the beginning. Related to this point as well is the use of buffers that in the traditional perspective were not considered. These ones act as a cushion to absorb the necessary time for the mentioned corrective actions if needed, so it is very important to consider them.

The data gathering showed that with the actual approach of the project, a higher level of coordination was required. Given the optimization results, it could happen that a change in the perspective introducing the use of LBMS would be beneficial towards coordination matters in the project. At least it would be a prerequisite for this coordination to be improved.

In the initial project data there were activities happening in parallel. During the optimization of the solution, since there was not specific data available about the resource usage for each activity given, it was assumed the allocation of one standard

crew for each activity even though the existent mentioned parallelism. After combining the activities in tasks, and to avoid the collision between those, the alignment of the tasks was performed. This alignment requires a change in the labor rates. If we assume that such rates are given and therefore will not be changed, there is a need to increase or decrease the resources used so the rhythms of the tasks are synchronized. Hence, the optimization implies a change from the initial assumption of one crew/resource per activity to an adapted amount of resources for the new progress requirements.

As for the tasks continuity, this has been a main goal for the optimal solution. The reason is to ensure a smooth transition within locations. If we consider a crew with non-continuous work scheduled, this means that their work will be set according to fixed starting and finishing points in the schedule. Every start implies to set up the work rhythm, which most likely happens gradually. If the activity itself depends on other predecessors, this starting point will not happen until those activities are performed, and their outcomes will establish how the starting will be as well. Procurement activities should be considered in this case as well, and there will be a need to plan more procurement than if the work is set as continuous. If the established working rate is not reached, the finish may be also compromised affecting subsequent activities. Therefore, it is preferred a continuous task progressing along the project locations in terms of productivity. For a subcontractor, continuity will also ease the use of its resources in its project portfolio since its distribution will not happen along time intervals.

6. CONCLUSIONS

6.1 General conclusions

- A LBMS is a planning management system that integrates all the phases of a construction project, from its design to its completion. Its development arises as the answer to the requirements that the traditional planning systems did not fulfill. The main difference with the traditional approaches is the use of the project locations as units of analysis instead of the tasks.
- LBMS focus in the workflow and its continuity and it is based in a *five layered-logic principles* which have their roots in the logic applied in the logical network planning methods as CPM or PERT.
- LBMS have a close relation with lean construction and they share some principles that are applied in an iterative process pursuing production perfection:
 - Minimization of the waste in the project flows.
 - Increase of the productivity.
 - Decrease of the variability to take advantage of activities repetition and standardization of processes.
 - Use of *pull* mechanisms to activate production instead of *push*. In LBMS the project locations are the pulling mechanisms.
- LBMS uses *flowline schedules* as graphical representation for the project tasks in a time plan. The main difference with the commonly used Gantt charts is the implementation of a 2-axis diagram with a time scale in the x-axis and a location scale in the y-axis. This results in a linear representation of the tasks' progress along the project in a very intuitive way. The slope of the lines will set the working rate for each task, which will be defined by the locations, time and resources' constraints.

- A prerequisite for the creation of flowline schedules is the *location-breakdown structure (LBS)* of the physical locations of the project. The LBS divides the project in a hierarchical system of different levels defining the units of study, which will integrate the data to be used iteratively in the project.
- In LBMS, a task is defined as the sum of the activities of similar nature that will be performed by the same resources in a sequential manner along the project locations. This definition gives room to group repeated activities while implementing standard procedures, reducing variability and singularity of the tasks. Thus, iteration can be undertaken to improve such procedures and improve productivity.
- Flowline schedules can be optimized using a geometrical approach. Hence, the lines representing the different tasks can be aligned giving them the same slope. Once the working rhythm of the project tasks is encompassed, the resources needed to reach such working rates could be computed. The innovation here is that aligning tasks may result in a reduced number of resources needed in some cases.

6.2 Conclusions of the case study

- Implementing the optimization of the flowline schedule in a real case has proved to be beneficial for the project for both the tasks' continuity and resource planning issues. For the case of the tasks' continuity, this optimization has led to the creation of an ordered and continuous workflow along the project. This is positive to improve the coordination among the subcontractors and different activities performed; it eases the planning itself and contributes to more effective ways to follow up the project progress based in actual data and creation of forecasts.
- The creation of a continuous workflow has also an impact in the resources usage, which becomes more systematic since the same resources perform a standardized activity along different locations. This contributes to the iterative process of improvement of the construction process. The way in which resources are allocated, considering not just the labor rates but also the spaces they will occupy in the project itself, provides a sequential way of working which tries to avoid overlapping tasks and resource collisions with the potential threat these represent for the schedule to be delayed and the quality of the outcomes to be jeopardized.

7. FURTHER WORK

The study undertaken in this thesis gives just a glimpse of the potential of the use of LBMS in construction. Furthermore, the optimization problem described has been limited just to two aspects: task continuity and resource balance. These are far to cover the whole optimization prospect. Thus, a further study is suggested to process an optimal solution of the problem taking into account all the variables that here were neglected.

At the same time, the use of VICO Office has been limited to one of its modules. As seen theoretically in the description of the software workflow, it has a great number of possibilities for planning under LBMS. A wider study could contemplate the integration of its modules to undertake a full analysis, starting from the 3D model and going through its 4D (cost analysis and planning) and 5D (scheduling).

Despite all the studies pointing out the benefits of the location-based methods of planning, users of the traditional planning approaches seem to be reluctant to change their minds and ways of working. There is a serial of aspects that are involved in this matter. The first one has to be with the experience acquired about the traditional methods and the willingness to learn new theories and practices, which require investment in both time and money. But also other aspects as the inherent complexity and uncertainty in construction projects (briefly discussed above) may be reasons for the slow deployment of LBMS in construction. All of these points would be worth to be studied in future research projects.

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APPENDICES

A. Master Thesis task

MASTER DEGREE THESIS

Spring 2013

for

Student: Natalia Rodríguez Martínez

Optimization of flowline scheduling vs. balanced resources and task continuity

BACKGROUND

This project is a part of the specialization for the MSc in Project Management within the Civil and Transport Engineering department (BAT). It has as starting point the basis set with the specialization project the previous semester, where lean construction was the topic under consideration.

This thesis will focus in location-based management (soneplanlegging) and its tools, which is closely related with lean construction. Among the tools used in this management system are the flowline charts where task management in projects is not only based in a time scale, but also in the allocation of resources in the different physical locations of the project.

TASK DESCRIPTION

The main task for this thesis is the optimization of the flowline charts used in location-based management to find a solution for scheduling where also resources distribution and task continuity would be optimal. This should be done taking into consideration the lean construction philosophy and its goals towards waste elimination and pursuing of processes perfection.

General about content, work and presentation

The text for the master thesis is meant as a framework for the work of the candidate. Adjustments might be done as the work progresses. Tentative changes must be done in cooperation and agreement with the professor in charge at the Department.

In the evaluation thoroughness in the work will be emphasized, as will be documentation of independence in assessments and conclusions. Furthermore the presentation (report) should be well organized and edited; providing clear, precise and orderly descriptions without being unnecessary voluminous.

The report shall include:

- Standard report front page (from DAIM, <http://daim.idi.ntnu.no/>)

- Title page with abstract and keywords.(template on: <http://www.ntnu.no/bat/skjemabank>)
- Preface
- Summary and acknowledgement. The summary shall include the objectives of the work, explain how the work has been conducted, present the main results achieved and give the main conclusions of the work.
- Table of content including list of figures, tables, enclosures and appendices.
- If useful and applicable a list explaining important terms and abbreviations should be included.
- The main text.
- Clear and complete references to material used, both in text and figures/tables. This also applies for personal and/or oral communication and information.
- Text of the Thesis (these pages) signed by professor in charge as Attachment 1..
- The report must have a complete page numbering.

Advice and guidelines for writing of the report is given in: “Writing Reports” by Øivind Arntsen. Additional information on report writing is found in “Råd og retningslinjer for rapportskrivning ved prosjekt og masteroppgave ved Institutt for bygg, anlegg og transport” (In Norwegian). Both are posted on <http://www.ntnu.no/bat/skjemabank>

Submission procedure

Procedures relating to the submission of the thesis are described in DAIM (<http://daim.idi.ntnu.no/>). Printing of the thesis is ordered through DAIM directly to Skipnes Printing delivering the printed paper to the department office 2-4 days later. The department will pay for 3 copies, of which the institute retains two copies. Additional copies must be paid for by the candidate / external partner.

On submission of the thesis the candidate shall submit a CD with the paper in digital form in pdf and Word version, the underlying material (such as data collection) in digital form (eg. Excel). Students must submit the submission form (from DAIM) where both the Ark-Bibl in SBI and Public Services (Building Safety) of SB II has signed the form. The submission form including the appropriate signatures must be signed by the department office before the form is delivered Faculty Office.

Documentation collected during the work, with support from the Department, shall be handed in to the Department together with the report.

According to the current laws and regulations at NTNU, the report is the property of NTNU. The report and associated results can only be used following approval from NTNU (and external cooperation partner if applicable). The Department has the right to make use of the results from the work as if conducted by a Department employee, as long as other arrangements are not agreed upon beforehand.

Tentative agreement on external supervision, work outside NTNU, economic support etc.

Separate description to be developed, if and when applicable. See <http://www.ntnu.no/bat/skjemabank> for agreement forms.

Health, environment and safety (HSE) <http://www.ntnu.edu/hse>

NTNU emphasizes the safety for the individual employee and student. The individual safety shall be in the forefront and no one shall take unnecessary chances in carrying out the work. In particular, if the student is to participate in field work, visits, field courses, excursions etc. during the Master Thesis work, he/she shall make himself/herself familiar with “ Fieldwork HSE Guidelines”. The document is found on the NTNU HMS-pages at <http://www.ntnu.no/hms/retningslinjer/HMSR07E.pdf>

The students do not have a full insurance coverage as a student at NTNU. If you as a student want the same insurance coverage as the employees at the university, you must take out individual travel and personal injury insurance.

Start and submission deadlines

The work on the Master Thesis starts on January 16, 2013

The thesis report as described above shall be submitted digitally in DAIM at the latest at 3pm June 11, 2013

Professor in charge: Olav Torp (NTNU)

Other supervisors: John Skaar (Skanska Norge AS)

Trondheim, December 13, 2012. (revised: dd.mm.yyyy)

Olav Torp (sign)

B. Tools

This appendix contains the tools mentioned during the methodology used to sort and process the information sources. The next table is an extract of the spreadsheet used to keep track of the status of the search according to the keywords used.

DATABASE/SOURCE

KEYWORDS	SCOPUS	SCIENCE DIRECT	GOOGLE SCHOLAR	KNO VEL	BIBSYS (MASTER THESIS)	SKANSKA	Lean Const. journal	Journal of construction engineering and management
Location based management/ planning/ scheduling								
Soneplan- legging								
Flowline planning/ scheduling								
Skråstreks- planlegging								
Logical Network methods								
CPM								
PERT								
Resource planning								
Resource balance/ leveling/ loading								
Task/work continuity								
Work flow								

Table 7 - Keywords and Sources table

Snapshot of EndNoteX6 with the key groups in the left ribbon, the list of references used in the thesis report and a selected article attached.

The screenshot shows the EndNote X6 interface. On the left, the 'My Library' pane is expanded to show '0-REPORT REFEREN...' with 44 references. The main pane displays a list of references with columns for Author, Year, and Title. The selected reference is 'Kenley, R.; Seppänen, O. 2009b Location-based management of construction projects: Part of a new typology'. The right pane shows a preview of the article 'LOCATION-BASED MANAGEMENT OF CONSTRUCTION PROJECTS: PART OF A NEW TYPOLOGY FOR PROJECT SCHEDULING METHODOLOGIES' by Russell Kenley and Olli Seppänen. The article includes an abstract and an introduction section.

Author	Year	Title
Jongeling, Rogier; Olo...	2007	A method for planning of work-flow by combined use of location-based sc
Kalsaas, BT; Skaar, J; T...	2010	System og resultater fra utprøving av planleggingsmetoden "Last Planner"
Kang, L.; Park, I.; Lee, B.	2001	Optimal Schedule Planning for Multiple, Repetitive Construction Process
Kastor, A.; Sirakoulis, K.	2009	The effectiveness of resource levelling tools for Resource Constraint Proje
Kelley Jr, James E; Wal...	1959	Critical-path planning and scheduling
Kenley, R.	2005	Dispelling the complexity MYTH: Founding lean construction on location-ba
Kenley, R.; Seppänen, O.	2009a	Location-Based Management for Construction: Planning, Scheduling and Cont
Kenley, R.; Seppänen, O.	2009b	Location-based management of construction projects: Part of a new typolo
Koskela, Lauri	1992	Application of the new production philosophy to construction
Koskela, Lauri	2000	An exploration towards a production theory and its application to construct
Leu, S. S.; Hung, T. H.	2002	An optimal construction resource leveling scheduling simulation model
Linge, G.	2012	Trimmet bygging
Lowe, R.H.; D'Onofrio,...	2012	A Comparison of Location-Based Scheduling with the
Midt-Norge, Helsebygg	2012	NORGES STØRSTE SYKEHUSUTBYGGING
Narayanan, Veekay K; ...	1993	Organization theory: A strategic approach
NTNU	2013	VIKO-Your guide to information literacy
Peer, Shlomo	1974	Network analysis and construction planning
Pinto, J.K.	2012	Project Management: Achieving Competitive Advantage
The student room	2011	Resource histogram
Sacks, R; Partouche, R	2009	Empire State Building Project: Archetype of "Mass Construction"
Saunders, Mark; Lewis...	2011	Research Methods For Business Students, 5/e
Seppänen, Olli; Kankai...	2004	Empirical research on deviations in production and current state of project
Skaret, O.M.	2012	Porsche-takt på Kunnskapsenteret (Veidekke)
VICO Software	2008	Control 2008 User Guide
VICO Software	2010	The path to 5D BIM
VICO Software	2012	Vico Office R4.0 Help File
VICO Software	2013	Vico Office Production Controller Video Tutorials
Thomas, R.M.	2003	Blending Qualitative and Quantitative Research Methods in Theses and Dis

Figure 29 - EndNoteX6 snapshot

C. Case Study

a. The project outline

Pictures from the outside of the buildings 21 (in white color) and 23 (in black color):



Figure 30 - Schweigårdsgate 21-23 outline (Lund+Slaatto Arkitekter, 2013)

Architectural detail of the interior design.

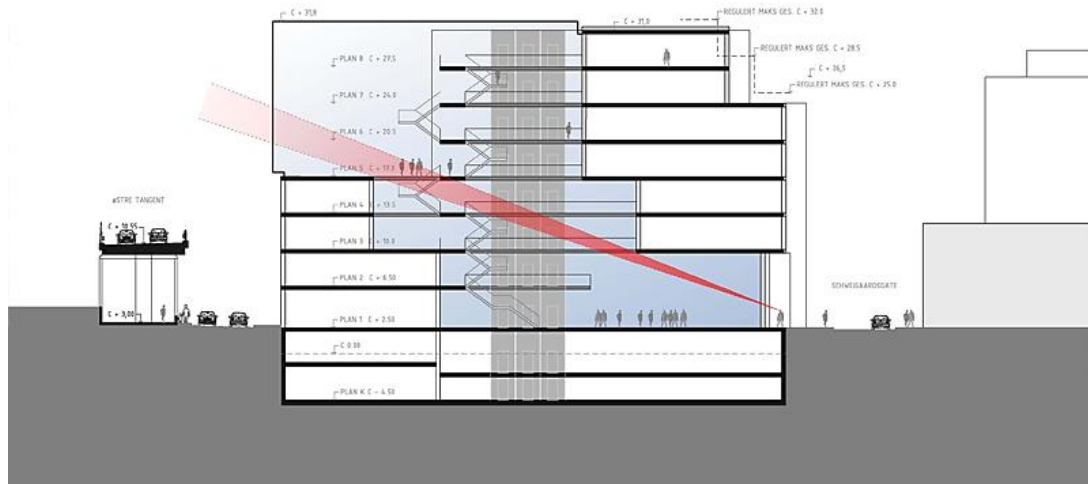


Figure 31 – Case study interior design (Lund+Slaatto Arkitekter, 2013)

Plan of the project, in this case of floor nr. 3.

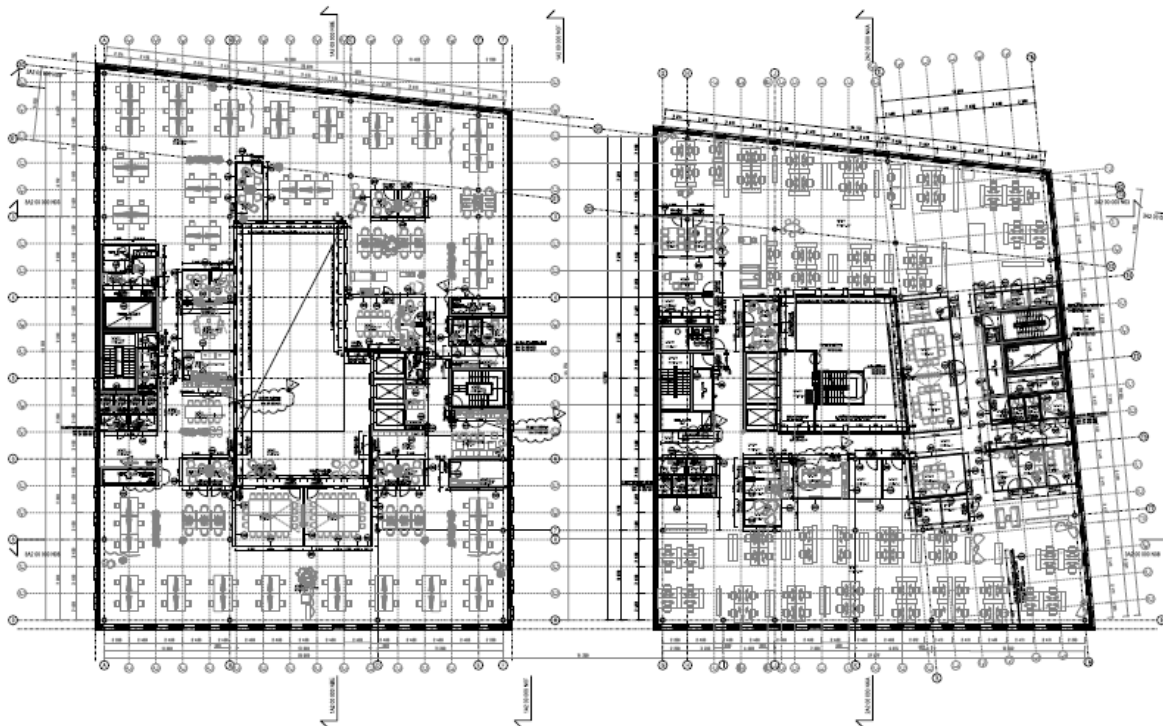


Figure 32 – Case study plan

b. Interview to Lars Aasen

WORKFLOW

1. Do you know/Have you applied lean construction practices when planning and development of this project? Yes

- **What do you understand for workflow?**

Workflow applies when there is repetition of activities. Therefore, there can be a certain degree of standardization.

In this project, the different building floors are considered as units of similar characteristics. So we can plan the same activities in the different areas. In addition, we can plan the activities sequence, both in floor and building levels. A concept that can be apply is a 'train' which sets the movement along the project. It is better and cleaner if this 'train' goes from top to bottom of the project, which is easier to implement in rehabilitation than in new projects.

In the floor level, one has to make a path to follow (a map) of the activities and milestones workers should follow within each area. This means there is a 'start' point where activities must start and, in addition, there are some other points where activities must be finished before the next ones can start.

- **Have you received any specific training related with lean construction?**

Yes, a course with Skanska. People working in this project know about lean construction principles but not because they have had specific learning, this is because of their experience at work.

2. Is the project following the established plan or is it experimenting delays?

There are delays. We can see them when filtering the completed activities in the MS Project document. We can also use other methods to follow up the façade's views (north-south-east-west) where we have a visual way to see which activities are finished and which should be finished.

- **If there are delays, why?**

There can be many reasons like small details that were not planned or the subcontractors' work which is not done as expected.

- **Were the different activities planned to follow a continuous workflow or are they planned in an interrupted sequence?**

They were planned as continuous as possible so the subcontractors could work continuously.

- **Are there collisions between tasks working in the same areas?**

There are different activities happening in the same areas (floor), but these are big enough to avoid collisions between activities. There is also zoning (location division) within each floor but not in a very small level.

- **Is there a greater need for coordination between different tasks and subcontractors than the planned one?**

The coordination planned is quite big and it is done in collaboration with the subcontractors (involvement planlegging) with a very accurate plan (in comparison with some years ago). It could always be improved.

3. How was the involvement of the subcontractors with Skanska in the planning/scheduling of the project tasks? (Low/Medium/High)(From an early stage of planning/Later in the process)

Subcontractors were involved from an early stage of the planning and they are highly involved in the process. Skanska is the one making the plan in collaboration with the subcontractor, taking their inputs into account. Afterwards, Skanska approves the plan if it applies.

4. Any other comment about the workflow in the project?

Plans don't always go as expected and there are some important points to think about:

- Thinking in the different floors as equal units to plan the activities repetition.
- Setting the start-stop of the activities in the different zones. In addition, activities should start on Monday, if possible.
- Thinking in the 'train' motion from top to bottom (or from bottom to top, if there are time or other constraints that make it impossible).

RESOURCING

1. Is the resource loading (crew design) optimal for the expected performance and progress of the tasks?

It is optimal according to the subcontractors' experience. They are who decide how many men they need to undertake a task (this depends on the available time and space to work). Skanska approves or not those calculations afterwards. Experience is very important at this point.

- **Do the crews need to work overtime to accomplish the schedule?**

Yes, they work overtime when there are working delays. Normally they work from 7 AM to 8 PM, from Monday to Friday, and Saturdays if necessary.

2. Are there different crews performing different tasks in a same area simultaneously?

Yes, but the areas are big enough and the atmosphere between the different crews is good.

- **Does this have any negative impact in performance? (limited space, too many people)**

This does not have an effect in the work performance, just in the timeplan.

- **Is this affecting the project schedule?**

This means delays in the plan.

3. How has the resource planning been done? Which methods/labor rates have been used for resource loading?

The subcontractors choose how many men they need according to the time/space limitations, in collaboration with Skanska (See question nr.1). There is a matrix method which is used for this purpose (Week-Activity which gives the total needed number of workers in the building site at a determined time).

Task-Week	Week1	Week2	...	Week n
Task1	4	2		3
Task2	1	4		2
...				
Task n				
Total workers	5	6		5

Figure 33 - Resource loading matrix (Lars Aasen)

- **Have the subcontractors and Skanska collaborate to plan the resource loading, or has been done just by the subcontractors/Skanska?**

In collaboration Skanska-Subcontractors.

- **Was it done realistically if comparing the base working rates and actual performance?**

It is done more accordingly to the subcontractors' experience about the possible performance of the crews for a determined activity.

4. Any other comment about resourcing in the project? No

c. Questionnaire to the subcontractors

WORKFLOW

1. Do you know/apply lean construction practices when working in this project?
 - What do you understand for workflow?
 - Have you received any specific training related with lean construction?

2. Are the tasks that you are performing in this project scheduled following a continuous flow or are they interrupted?
 - Does this have a good or bad effect in your performance in terms of productivity?
 - Are there collisions between tasks working in the same areas?
 - Is there a greater need for coordination between different tasks and subcontractors than the current one?

3. How was your involvement with Skanska in the planning/scheduling of the project tasks? (Low/Medium/High)(From an early stage of planning/Later in the process)

4. Any other comment about the workflow in the project?

RESOURCING

1. Is the resource loading (crew design) optimal for the expected performance and progress of the tasks?
 - Do the crews need to work overtime to accomplish the schedule?

2. Are there different crews performing different tasks in a same area simultaneously?
 - Does this have any negative impact in performance? (limited space, too many people)
 - Is this affecting the schedule?

3. Has the resource planning been done in collaboration with Skanska?
 - Was it done realistically if comparing the base working rates and actual performance?
 - Which methods have been used for the resource allocation and leveling?

4. Any other comment about resourcing in the project?

ANSWERS

WORKFLOW	
How many know/use lean construction in this project?	10 out of 21 (7 from Skanska use it)
Understanding of the concept of workflow	<i>different definitions</i>
How many had specific training about lean construction?	6 out of 21 (4 from Skanska)
How many planned their work according to a continuous flow in the project?	14 out of 21
Relation performance-continuous flow	<i>different definitions</i>
How many see collision between activities?	18 out of 21
How is the need for coordination in the project?	17 out of 21 think more coordination is needed
How is the involvement in the planning?	High (8 out of 21), Medium (9 out of 21), Low (2 out of 21). 2 didn't answer 2 said is from a late time in the planning 3 said is from an early time in the planning

RESOURCES	
How many think the resources (crew design) is optimal?	13 out of 21
How many work overtime?	14 out of 21
How many crews work with other crews at the same time (different tasks simultaneous in same location)?	16 out of 21
Effect in performance?	10 out of the 16 working with other crews simultaneously had negative effect in performance
Effect in time plan?	11 out of the 16 working with other crews simultaneously had negative effect in the schedule (delays)
How many have collaborated with Skanska (if they are not Skanska) in the resource loading?	8 (6 from Skanska and 2 from others) out of 21
Methods for resource loading used:	<i>different definitions</i>
Is the resource loading realistic according to labor rates?	16 out of 21 say is realistic, 5 say is not

Table 8 - Questionnaire answers

d. Tasks considered in the case for the optimization

The selected tasks are the correspondent with the structural works in the building 23, considering the limitations and assumptions explained in 4.5.1 *Limitations and assumptions*. These tasks are the ones that have been introduced in VICO Schedule Planner for further optimization.

	Task number	Task navn	Task name
Floors	1	Ferdig tak tekking av dekke over K1	Finish roof thatching over K1
	2 (2-1 to 2-8)	Stål og elementmontasje	Steel and elements assembly
	3 (3-1 to 3-8)	Brannisolering av bjelker	Fire insulation of beams
	4 (4-1 to 4-8)	Kjerneboring gulv og vegger	Core drilling floor and walls
	5 (5-1 to 5-8)	Føringer i vertikale tekniske sjakter søppekanlegg	Holdings in vertical pipes for technical garbage plant
	6 (6-1 to 6-8)	Komplete skjørt	Complete skirt
	7 (7-1 to 7-8)	Hovedføringer sprinklermontasje	Main holdings for sprinkler assembly
	8 (8-1 to 8-8)	Montasje rammer til gulvbokser	Frame assembly for floor boxes
	9 (9-1 to 9-8)	Kabelbroer	Bridge cables
	10 (10-1 to 10-8)	Kursopplegg sterk og svak	Strong and weak course plan
	11 (11-1 to 11-8)	Hovedfremføring kjøling og sanitæranlegg	Main uphold for cooling and sanitary
	12 (12-1 to 12-8)	Hovedfremføring varme	Main uphold for heat
	13 (13-1 to 13-8)	Støvsugeanlegg over letthimlinger	Vacuum cleaner construction of lightweight ceilings
	14 (14-1 to 14-8)	Hovedfremføring drikkevannsystem	Main uphold for drinking water system
	15 (15-1 to 15-8)	Hovedføringer ventilasjon	Main uphold for ventilation constraints
	16 (16-1 to 16-8)	Tømrerarbeid klimavegg inkl spikerslag	Carpenter Working Conditions wall including nailing
24 (24-1 to 24-2)	Glassarbeid inngangsparti	Glass works in the entrance	
	17 (17-1 to 17-8)	Tømrerarbeid klimavegg elementmontasje	Carpentry works-insulation wall elements assembly
	18 (18-1 to 18-8)	Tømrerarbeid komplettering etter fasadeelementer	Carpentry works-finish after façade elements
	19 (19-1 to 19-8)	Montere vinkler til elementvegger	Mounting angles to the element walls

	20 (20-1 to 20-8)	Brannisolering av stål i fasaden	Fire insulation of steel facade
	21 (21-1 to 21-8)	Fasadestein klimavegger	Façade stone insulation walls
	22 (22-1 to 22-8)	Persienner klimavegger	Blind insulation walls
	23 (23-1 to 23-8)	Blikkenslager klimavegger	Beaters insulation walls
Roof	25	Gesimser tak råbygg	Cornices roof shell
	26	Provtetting av tak råbygg	Prov. Sealing of roof shell
	27	Tett tak råbygg	Tight control framework
	28	Glasstak tak råbygg	Glass roof roof shell
	29	Stålkonstruksjoner til fasadevasksystem tak råbygg	Structural steel for facade cleaning system control framework
	30	Kjerneboring tak råbygg	Coring roof shell
	31	Taksluk tak råbygg	Stormwater control framework
	32	Tømrerarbeid overganger stål tak, heishus og glasstak råbygg	Carpentry Work transitions steel roof, elevator case and glass shell
	33	Tekking tak råbygg	Roofing roof shell
	34	Montere glass i glasstak råbygg	Installing glass in glass shell
	35	Tett glasstak råbygg	Dense glass shell
	36	Kompletering glasstak råbygg	Complete Ring glass shell
	37	Beslag tak råbygg	Seizures roof shell
	38	Plasering av tørrkjølere tak råbygg	Place of dry coolers roof shell
	39	Tekniske føringer over tak rørlegger, tak råbygg	Technical constraints of roof plumbing, roof shell
	40	Tekniske føringer over tak ventilasjon, tak råbygg	Technical constraints of roof ventilation, roof shell
	41	Tekniske føringer over tak elektro, tak råbygg	Technical constraints of ceiling electrical, roof shell
	42	Værstasjon til solavskjerming, tak råbygg	Weather Station for shading, roof shell
	43	Fasadevasksystem montasje på bærestål tak råbygg	Face Wash System mounted on the supporting steel roof framework

Table 9 - Case study tasks

e. VICO outcomes

Case study flowline schedule previous to its optimization:

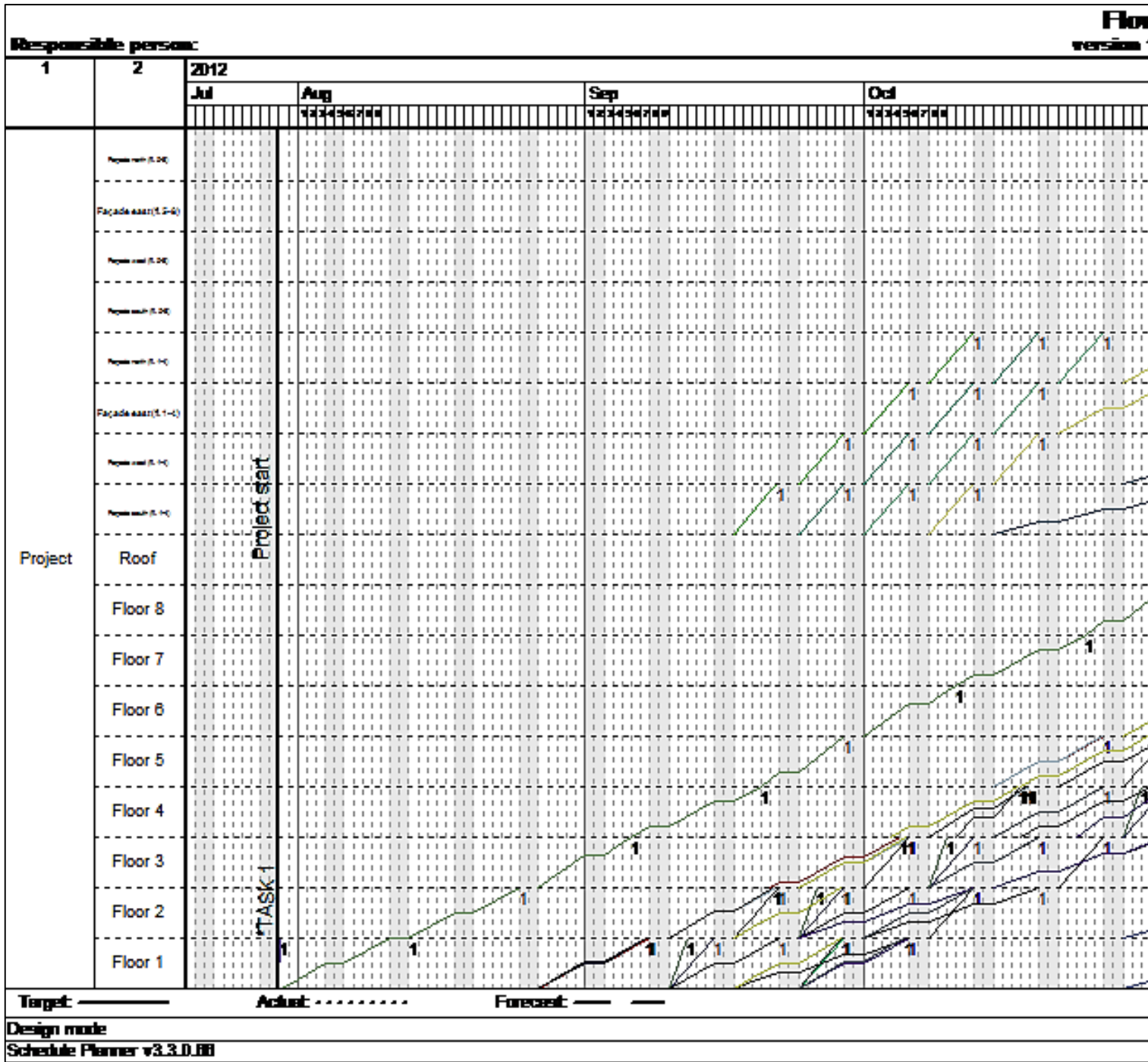
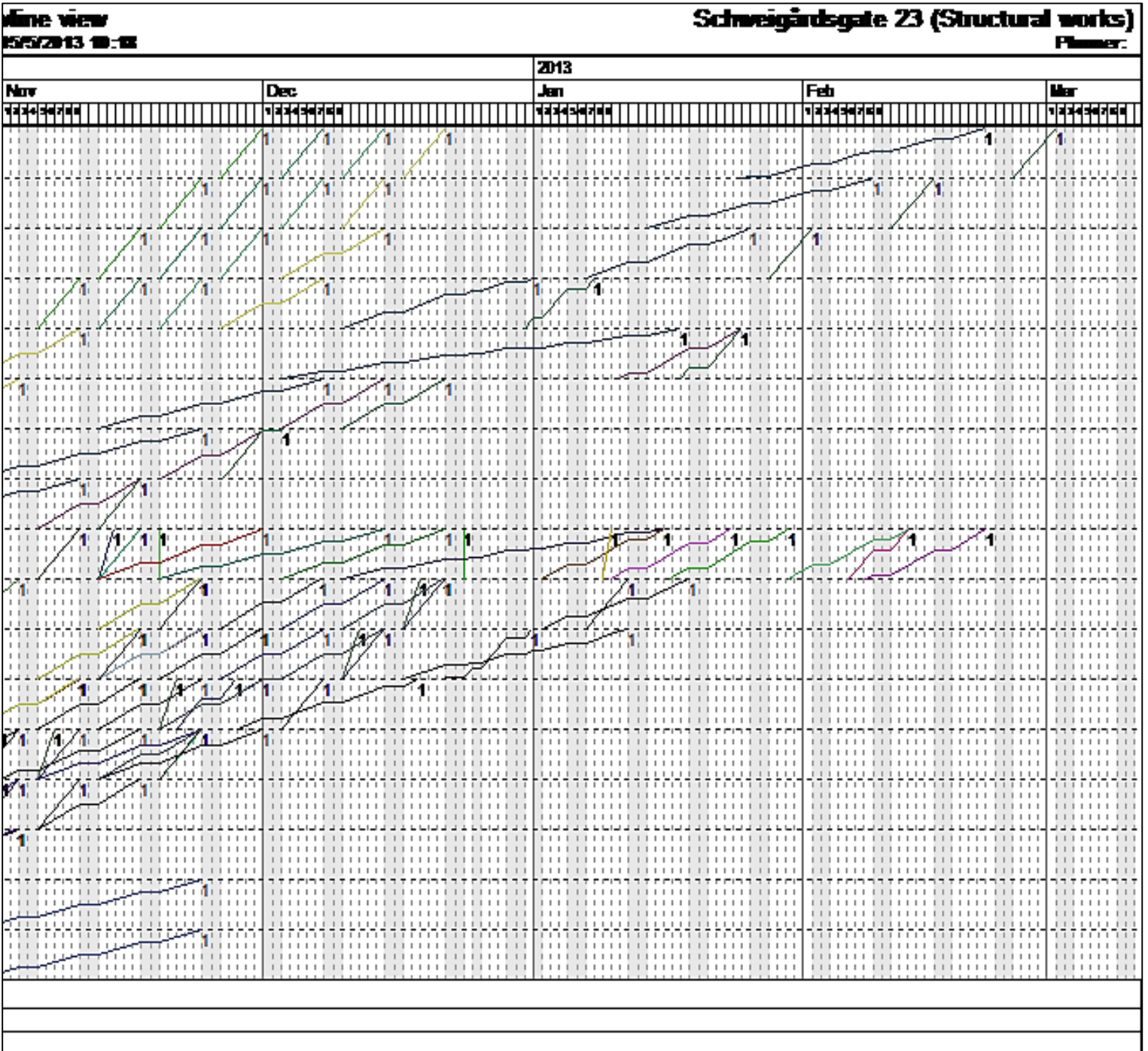


Figure 34 - Flowline schedule pre-optimized



Case study flowline schedule after its optimization:

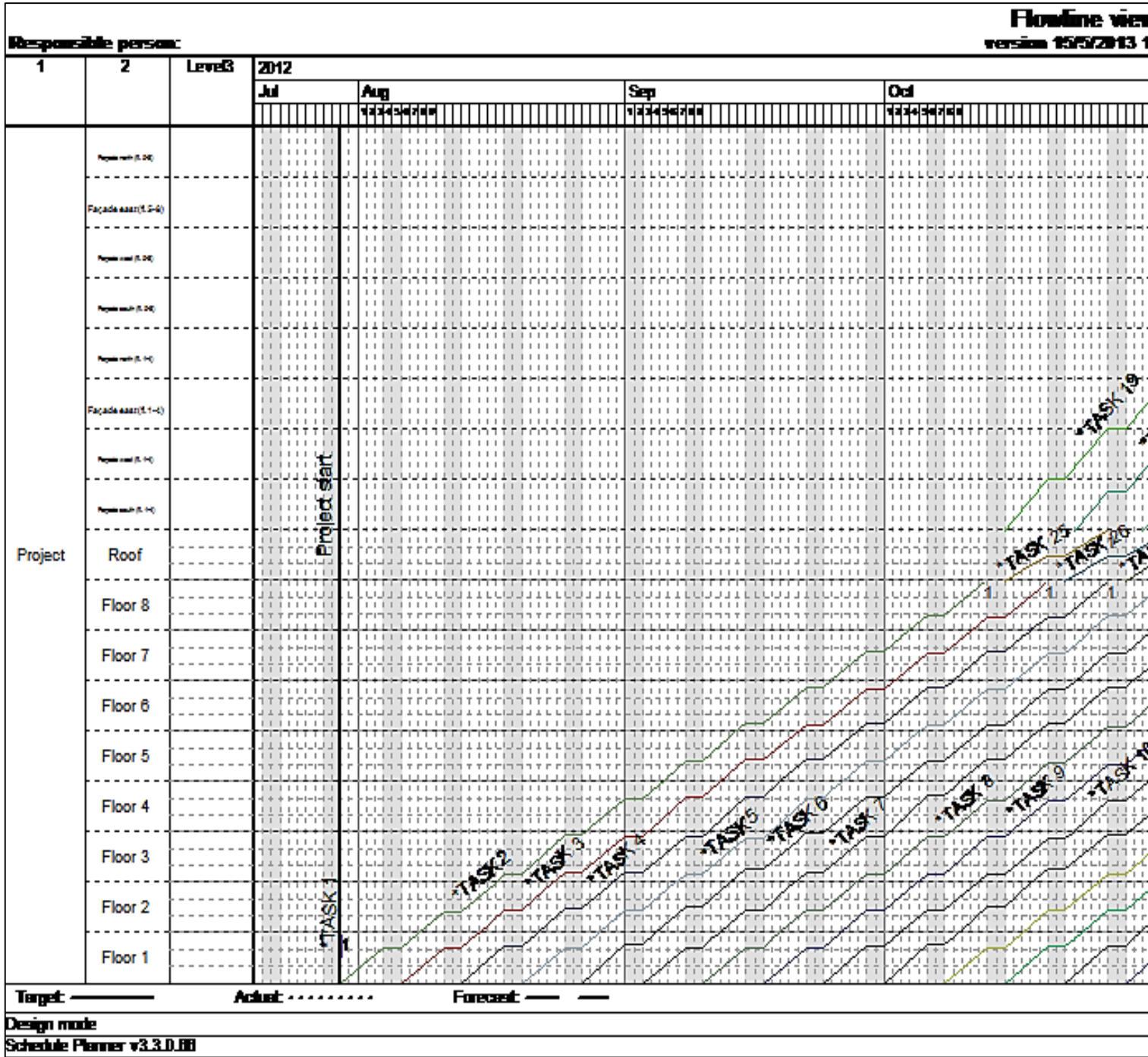


Figure 35 - Flowline schedule post-optimized

