Constructability Analysis of Monorail Project

Submitted to Prof. El-Diraby

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Abstract

Constructability is an important objective in the whole phases of a construction project, and experts with knowledge and experience play an important role in achieving superior constructability. Constructability analysis will help to eliminate hidden costs and change orders, ensure schedule, improve construction quality and enhance safety in construction project. This research is undertaken to conduct a constructability analysis of monorail project. We identify comprehensive factors which influence monorail project constructability during project planning, design and field operation. Through literature review and case study, a systematic approach and techniques to improve constructability in monorail project will be developed. Finally, we further develop a practical framework for constructability implementation in monorail project.

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1. Introduction

Constructability is a concept that has been pervasive for more than a decade in the construction industry (CII, 1986). Its quantifiable benefits from implementation have been well documented on many construction industry projects (CII, 1993). This paper concentrates on analysis of monorail constructability. So far we do find some literatures about constructability analysis of bridge (EI-Razek & Basha, 2001), highway (Anderson et al., 1999; Nima et al., 2002), industrial facility (CII, 1993) and office building (CII, 1993), but we haven't seen any formal analysis of monorail constructability. Lessons learned from monorail construction may have their genesis in any phase of monorail project's life cycle. Similarly, these lessons may be applicable to one or more phases of project life cycle. The constructability feedback model is shown in Figure1 (Kartam, 1996).

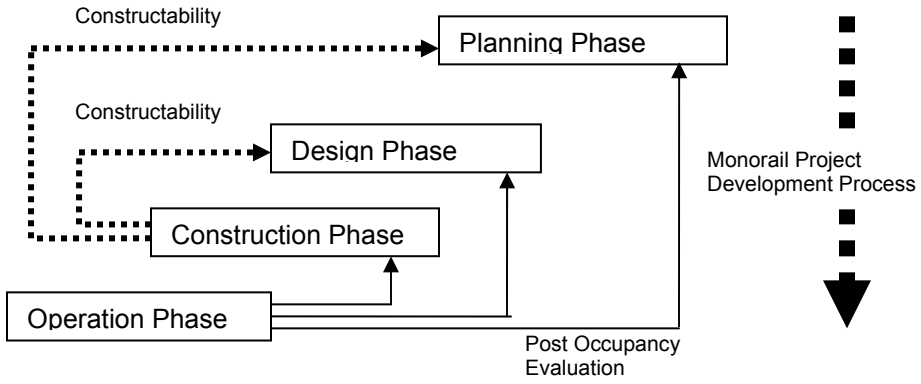

Figure1 Feedback of Constructability in Monorail Project Life Cycle

Due to the advantages of monorail in many transit realms, dozens of monorail systems have been built and in operating. Other many monorail projects are also in planning and under construction. There is a need to improve constructability of

monorail project by bridging gap between engineers and constructors in early stage of monorail project. This paper addresses this issue through formalizing the feedback system for construction knowledge. The following flowchart (Figure 2) describes the main research process of this paper.

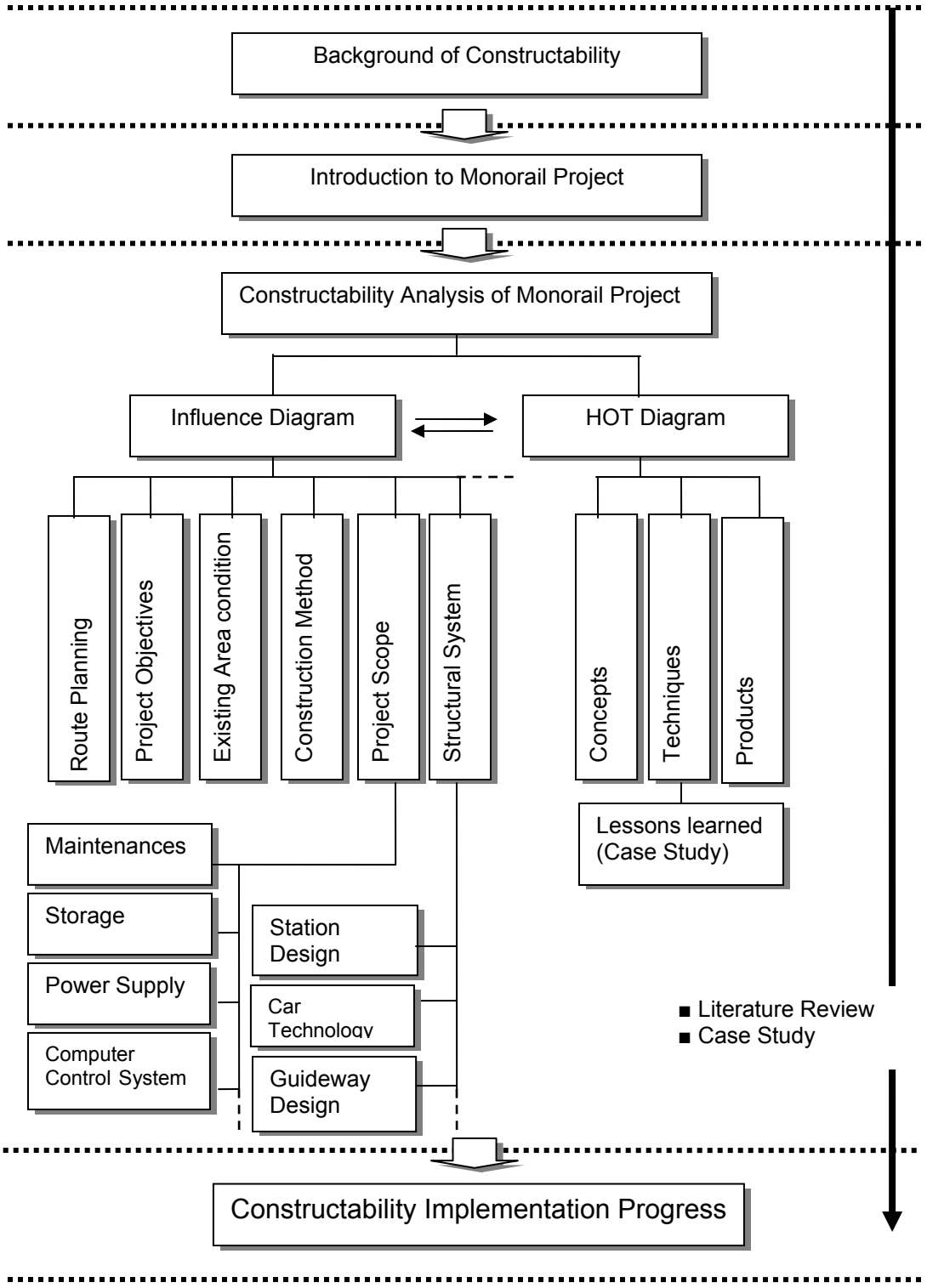

Figure 2 Research Process of Constructability Analysis of Monorail Project

2. Constructability

2.1 Definition of Constructability

The concept of constructability was introduced by CII (1986), in which it stated "Constructability is the optimum use of *construction knowledge and experience* in planning, design, procurement, and field operations to achieve overall project objectives" (CII 1986). Constructability is also defined as a measure of the ease of expediency with which a facility can be constructed (Hugo et al. 1990). Constructability is an "attitude" that must prevail through conceptual planning, design and procurement and field operations. If performed right, constructability has been shown to reduce construction cost, by 10 to 20 times its implementation cost (More 1983).

2.2 Benefits of Constructability

Constructability leads to some important benefits due to early integration of construction knowledge and experience into the engineering and design of a project. Constructability has demonstrated the potential to minimize the number and magnitude of changes, disputes, cost overturns, and delays during construction (CII 1986). Shortening construction time and improving project management by using constructability is expected to decrease overall project cost and thus reduce capital investment risk. The following are some direct benefits from constructability:

- Construction planning is made easier
- Both design and construction costs can be reduced

- Likewise the construction schedule may be shortened

- Better quality can be required and expected

- More realistic commitments can be made to subsequent trades, and to

- Earlier owner occupation

Indirect benefits are more difficult to quantify, but nevertheless include**:**

- Building a collaborative team committed to project goals

- Parties working for mutual benefit

- Cross discipline training

- Transfer of expertise from other projects

- Constructors better understanding design intent, and vice versa

- Increased innovation in both design and construction

- Shorter learning curves

- Competitive advantage

3. Monorail Projects

3.1 Definition of Monorail

Monorail is a single rail serving as a track for passenger or freight vehicles. In most cases rail is elevated, but monorails can also run at grade, below grade or in subway tunnels. There are two basic monorail types: straddle and suspension monorail. The straddle monorail runs on track beams which are mainly made of steel. Suspension monorail is suspended under track beams which are made of steel. Monorail vehicle are wider than the guideway that supports them. A monorail system comprises guideway, car, station, power supply equipments,

computer control systems and maintenance and storage facilities. A detail monorail system structure diagram is shown in Figure 3.

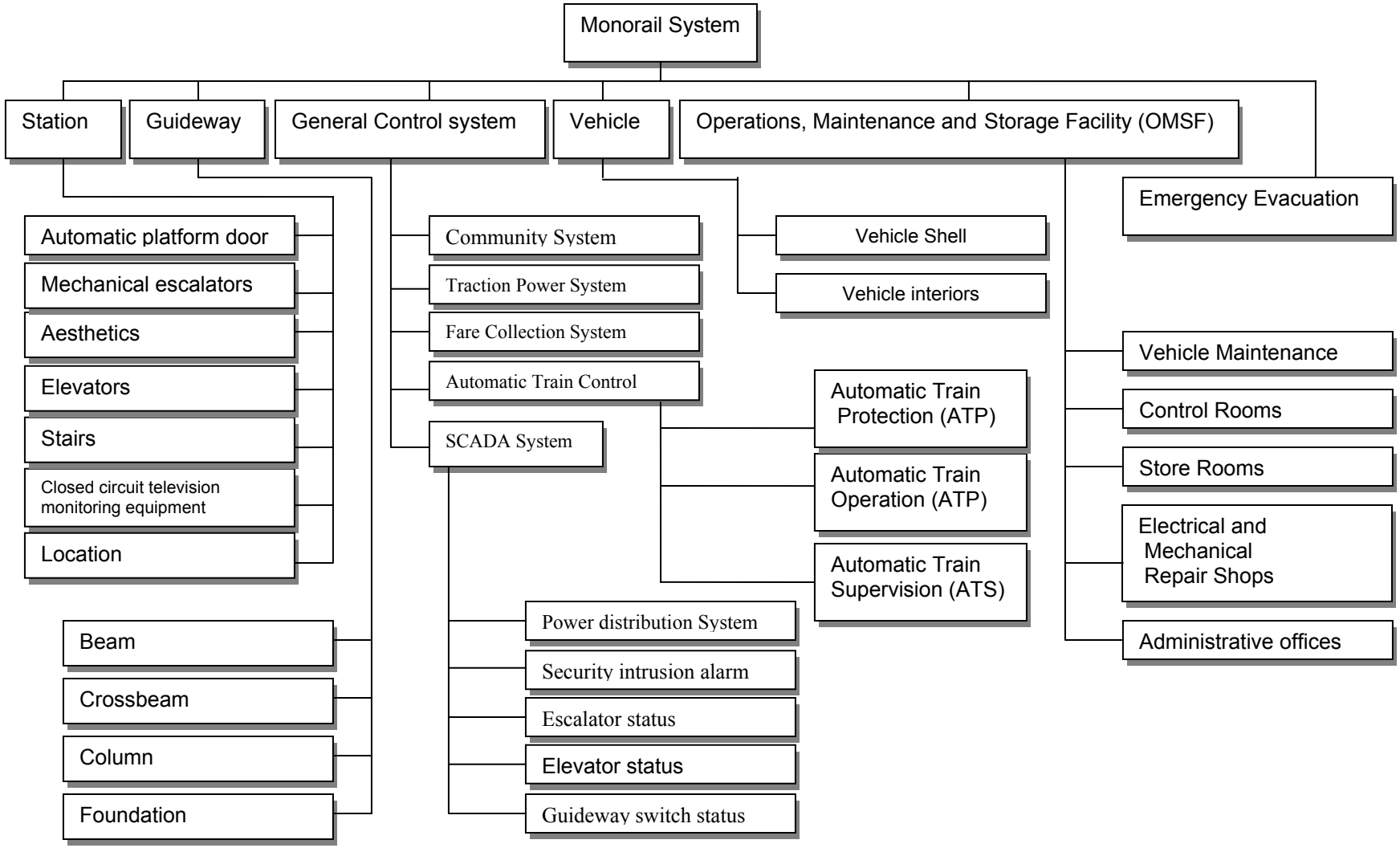

Figure 3 Structure of Monorail System

3.2 Examples of Monorail System

Dozens of monorail systems have been in operation or under construction around the world. Here several famous monorail systems will be introduced. Figure 4 shows the pictures of these monorail systems respectively.

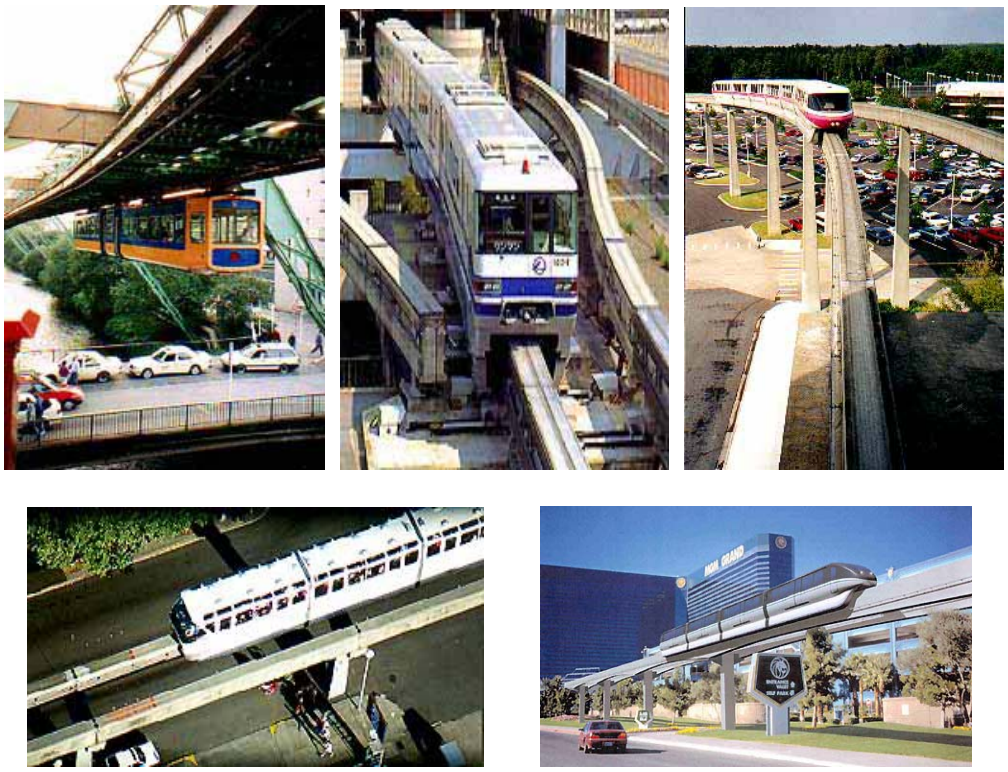

Figure 4 Wuppertal Monorail (top & left); Osaka Monorail (top & middle); Walt Disney World Monorail (top & right); Seattle Monorail (bottom & left); Las Vegas Monorail (bottom & right)[1].

1) Wuppertal, Germany

Urban monorail systems have been in regular passenger service for more than one hundred years, beginning with the Wuppertal suspended monorail system in Wupperal, West Germany. This 8 mile-long monorail system began service in 1901 and remains in service today linking 20 stations.

2) Osaka, Japan

[1] The Monorail Society, http://www.monorails.org/

The Osaka monorail emanates from the center of the city to connect surrounding area with a half circle system which will eventually surround the city with over 50 km of track. The first 6.6 km segment opened in 1990 north of Osaka. In 1995, the disastrous earthquake of nearby Kobe proved to be a test for the Osaka Monorail. It withstood the violent quake and proved to be a vital transit link in the area as traffic on the parallel freeway became completely jammed with evacuees.

3) Walt Disney World, Florida

Walt Disney world monorail began transit service in 1971. This 23.6 km long monorail system with 6 stations carries 150,000 passengers every day.

4) Seattle, Washington

Seattle monorail was opened in 1962. This 1.9 km long monorail with two stations carries 2.5 million passengers every year. In November of 1997, Seattle voters passed the Monorail Initiative to extend the system citywide.

5) Las Vegas, Nevada

Las Vegas monorail was opened in 1995 which is short (1.2km) and only has two stations, yet it carries more passengers (20,000/day) than some light rail systems that are fifteen times longer with far more stations. This privately built and owned monorail is a success story. Currently the system is being expanded the north to connect with other resorts and he Convention Center.

3.3 Merits of Monorail

Compared with the subway (heavy rail) and trolley (light rail), the monorail shows the following advantages (Aoki & Ishikawa, 1989):

1) Efficiency

Since the monorail vehicle uses a concrete or steel guidebeam for both the vehicle's running surface and structural support, less guideway maintenance is required. The monorail guidebeam does not require periodic adjustment, replacement, grinding, tightening, or other maintenance. The rubber tires get little wear running on smooth guideways.

2) Cost

While capital costs can be as much as or more than light rail, monorail can turn a profit once built. The Tokyo Monorail is operated by a private business and turns a profit each year. This is unheard of with conventional rail or bus systems. The Seattle Monorail also turns a profit each year.

3) Construction

Process of monorail construction is simple - dig a hole, drop in a pre-built support pylon, truck in the track which was manufactured offsite, lift into place! Monorail beamway can be installed far faster than the alternatives. Figure 5 shows a Las Vegas Monorail beam being put into place. From truck bed to pylons was a matter of a few minutes. The entire system took only seven months to construct. No other fixed rail can be installed as quickly and as disruption-free.

Figure 5 Simple Construction Process of Monorail

Figure 6 Environment-friendly Monorail

4) Aesthetics

The monorail guideway can be constructed to be an enhancement rather than a detriment to the environment. Monorail systems generally have a smaller footprint on the environment and the narrow guidebeams are less obtrusive than conventional trough-type guideways that are really more like aerial road structures. Figure 6 is the graceful arched guideway of the Walt Disney World Monorail System. The beam is only 26" wide with the small shadow.

5) Safety

Monorails run on an exclusive grade-separated guideway. So there is no possibility to collide with other vehicles. The ways by which monorails are designed also make derailments virtually impossible. This is why monorails have an excellent safety record.

4. Factors of Monorail Constructability

Monorail projects are often located in high density population area (such as downtown) and famous scenic spots. Its strategic objectives could be diversity, such as relieving traffic congestion, improving accessibility and visitor convenience, working commuting and shopping, providing a good imagine of the city for the visitors. Considering these characteristics of monorail, implementation of constructability program in monorail project has to enhance safety, improve efficiency, realize esthetics, reduce cost, ensure schedule and minimize impact on environment.

A typical life cycle of monorail includes planning, design, construction and operation and maintenance. Integration of lessons learned from construction into all phases of the monorail is beneficial. Constructability analysis bridges the gap

between engineering and construction early in monorail project to achieve possible full benefit. Constructability encompasses feedback loops emanating from the construction phase. Constructability is an input of construction knowledge and experience into all phases of a project. CII has shown that integration of construction knowledge into all project phases has resulted in paybacks of up to 15 to 1 (CII, 1993).

Figure 7 depicts the factors which should be considered in monorail constructability analysis in the early phases of a project for obtaining optimum project results. These factors coming from planning phase, design phase and construction phased would influence monorail construction.

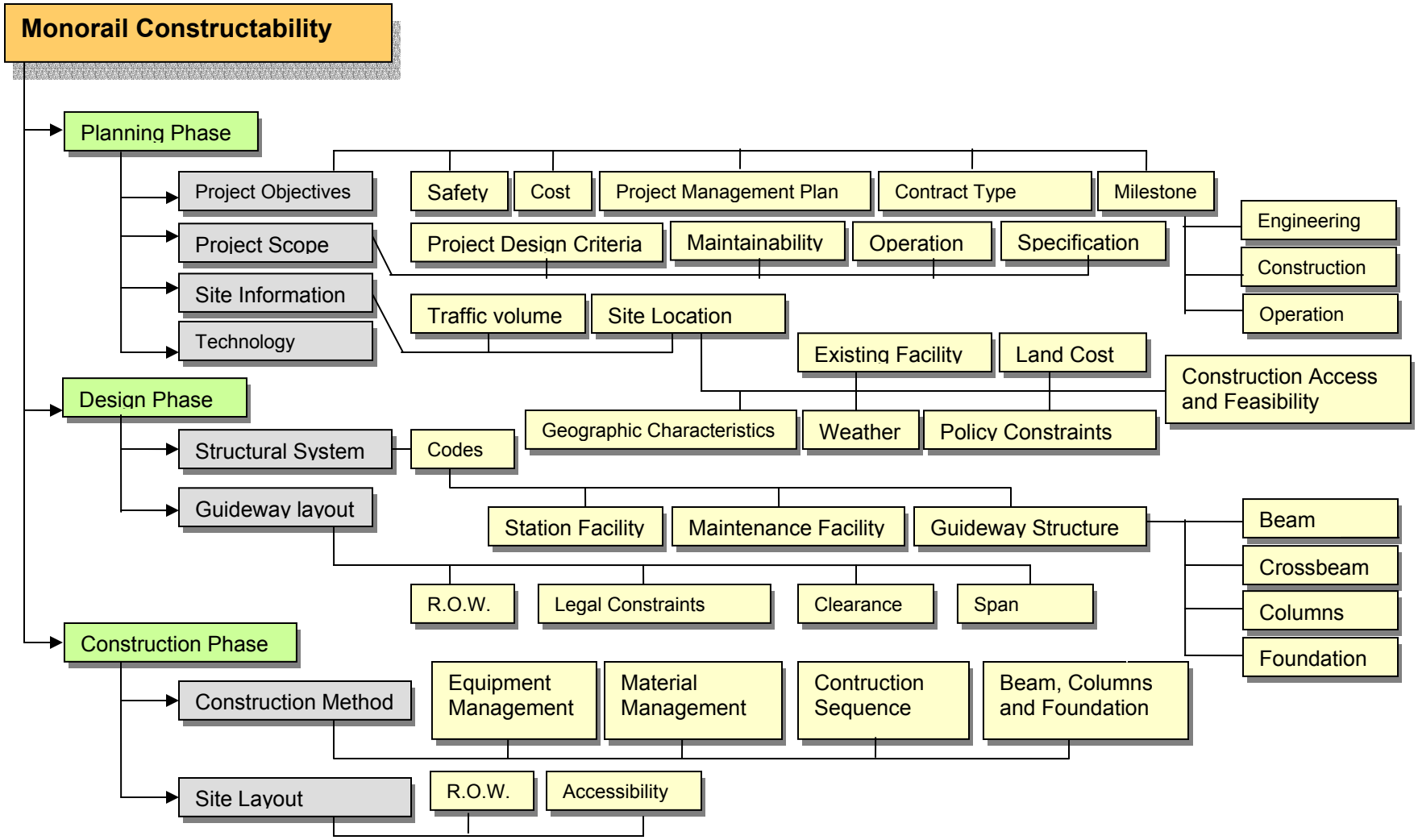

Figure 7 Influence Diagram of Monorail Constructability

1) Factors from Planning Phase

Research indicates that the planning phase is where the maximum investment returns are realized when constructability is considered in the whole project development process (CII 1986). An analysis of the constructability knowledge in the monorail planning indicates that the following planning factors are important for constructability of monorail projects.

□ Project Objectives

Constructability of project objectives means if these objectives could be realized in terms of construction, such as whether the budget is enough to construct the monorail; whether the milestones is feasible in specific construction phase, whether the contract types are suitable to ensure the successful completion of the project.

□ Project Scope

The project scope provides series of specification and maintenance & operation requirements for the construction of the monorail project. The specification and requirements which in fact resulted from construction knowledge and experience will instruct and influence the construction of monorail projects. Obviously, the process is iterative.

□ Site Information

Site information such as traffic volume, soil, weather and existing facilities will determine the feasibility and effects of the route planning, design and construction of monorail projects. Different site information will lead to different optimum construction for this specific project.

□ Technology

Different choice of technologies such as guideway structure (suspend or straddle), vehicle structure and control system will influence the construction methods. Better understanding different technologies, better implementing constructability based on different project conditions.

2) Factors from Design Phase

The reality of construction is that probably 75% the problems encountered in the field are generated in the design phase (Mendelsohn 1997). If we hope to reduce problems in the field for monorail projects, an obvious place to be emphasized is what we can do to catch these problems in the design phase.

□ Structural system

The structural system includes station facility, maintenance facility and guideway structure. It is a core issue in the design and construction of monorail projects. It will directly influence the efficiency, the whole cost, the schedule and the aesthetics of this project.

□ Guideway layout

Guideway layout involves specific variables such as clearance, span, and legal constraints. These different variables look like small issues, but they will influence the final efficiency and cost of the project.

3) Factors from Construction Phase

Factors from construction phase also play an important role in influencing the constructability of monorail projects. Barriers and problems encountered in the

construction could obviously stem from construction phase directly, except for the planning and design phases.

□ Construction Method

The whole monorail project will benefit from the optimum management of material and equipment, and innovative use of tools and equipment during field operation, by reducing cost and improving efficiency.

□ Site Layout

The condition of construction site such as the accessibility influences the choosing of the construction method and technologies. For example, the accessibility for the large scale construction equipments should be considered.

5. Hierarchy of Techniques (HOT) in Implementation of Monorail Constructability

5.1 Constructability Concepts

Construction industry institute (1993) formulated the 17 constructability concepts in order to apply them in different phases in the project development process, including the planning, design, and construction. The 17 constructability concepts are listed below according to their relation to the different development phases. Project constructability enhancement during the planning phase consists of concepts from C-1 to C-8:

- *Concept C-1*: Constructability program is an integral part of project execution plan.

- *Concept C-2*: Project planning involves construction knowledge and experience.

- *Concept C-3*: Early construction involvement in development of contracting strategy.

- *Concept C-4*: Project schedules are construction-sensitive.

- *Concept C-5*: Basic design approaches consider major construction methods.

- *Concept C-6*: Site layout promotes efficient construction.

- *Concept C-7*: Project team participants responsible for constructability are identified early.

- *Concept C-8*: Advanced information technologies are applied throughout project.

Project constructability enhancement during the design phase consists of concept from C-9 to C-16:

Concept C-9: Design schedule are construction sensitive.

Concept C-10: Designed to enable efficient construction.

Concept C-11: Design elements are standardized.

Concept C-12: Specification are developed for construction.

Concept C-13: Designed for modularization and preassembly to facilitate fabrication and transportation.

Concept C-14: Designed for accessibility of personnel, materials, and equipment.

Concept C-15: Designed for construction in adverse weather and remote locations.

Concept C-16: Design and construction sequencing should facilitate system turnover and start-up.

Project constructability enhancement during the construction phase comprises one concept C-17:

Concept C-17: Contractor use of innovative construction methods.

5.2 Hierarchy of Techniques (HOT)

Based on the constructability concepts above, we establish the hierarchy of techniques of constructability implementation for the whole monorail project development process including planning, design and construction phases. Figure 8 shows the HOT diagram for monorail project in which some important concepts, techniques and products featured in monorail construction are integrated. Lessons learned are collected from dozens of monorail project around the world being in operation or under construction, such as Seattle Monorail and Las Vegas Monorail. In Figure 9, we further develop a HOT diagram specifically for construction techniques.

Planning Phase

In the planning phase, some lessons learned from specific monorail projects, such as Seattle Monorail, Kitakyushu Monorail and Chiba will give some useful experiences on how to optimize station and route planning in planning phase, which will guide the best practice in monorail project construction, especially in promoting efficient construction.

Design Phase

Design is a complex and demanding process, but it is also the most fruitful area in optimizing the whole project schedule. Modularization and preassembly in design phase will simplify the construction process, ensure schedule and minimize the impact on the environment. Standardization of design elements is also desirable for any constructible design. Hence, to realize the constructability

in monorail projects, some codes are suggested to be followed in the monorail design phase.

Construction Phase

Construction knowledge and experience are also needed to improve the effectiveness of field operation. In the monorail construction phase, some Innovative construction methods should be considered, such as subcontract, construction techniques, and Innovations in materials, tools and equipment. For example, the monorail project in Walt Disney World apply a new material — composite material for carbody, which reduced the weight of the carbody and increase the transportation capacity of the train. Additionally, Traffic management should also be taken into account to minimize impact on existing traffic and environment, and provide efficient accessibility.

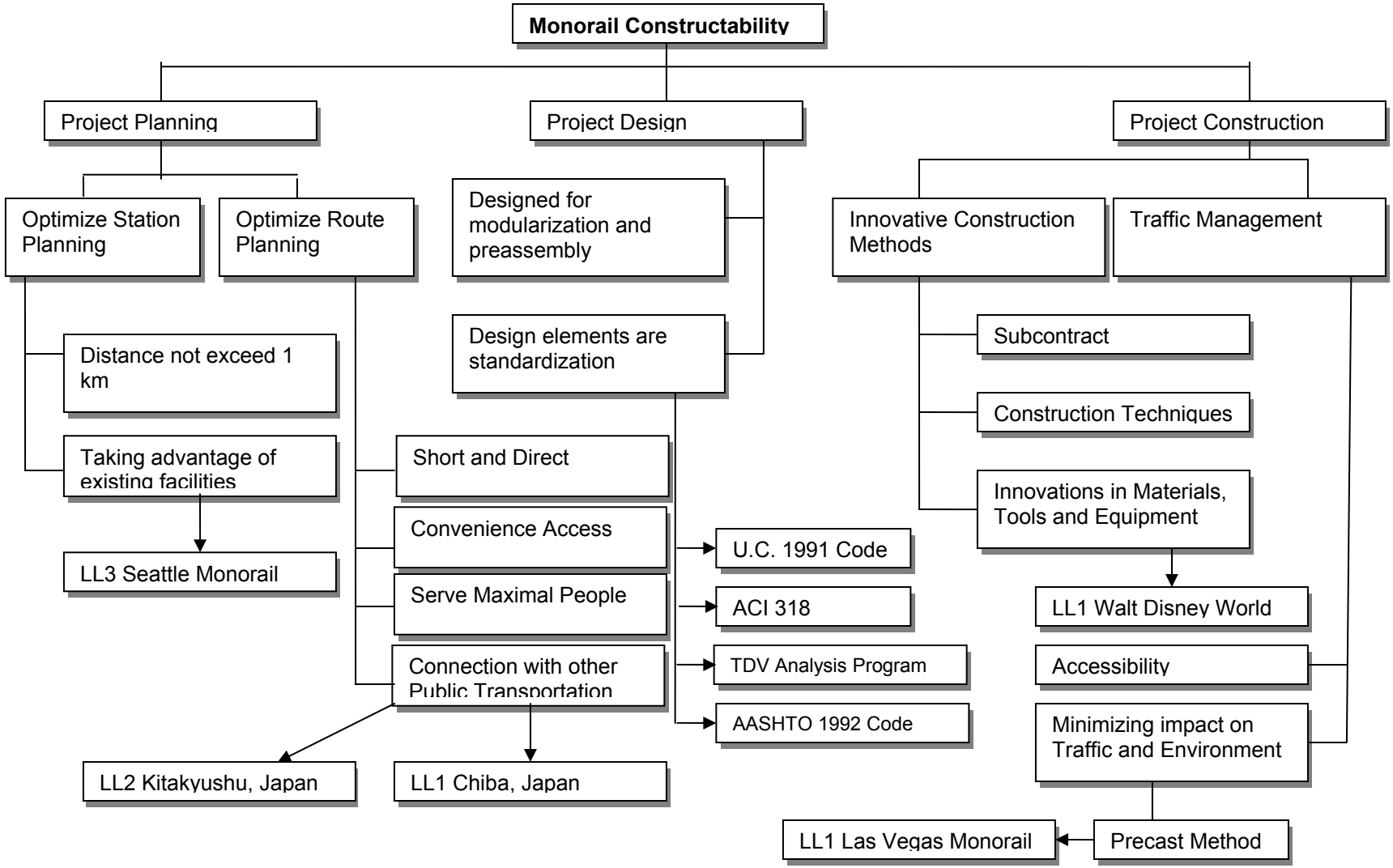

Figure 8 HOT Diagrams for Monorail Project

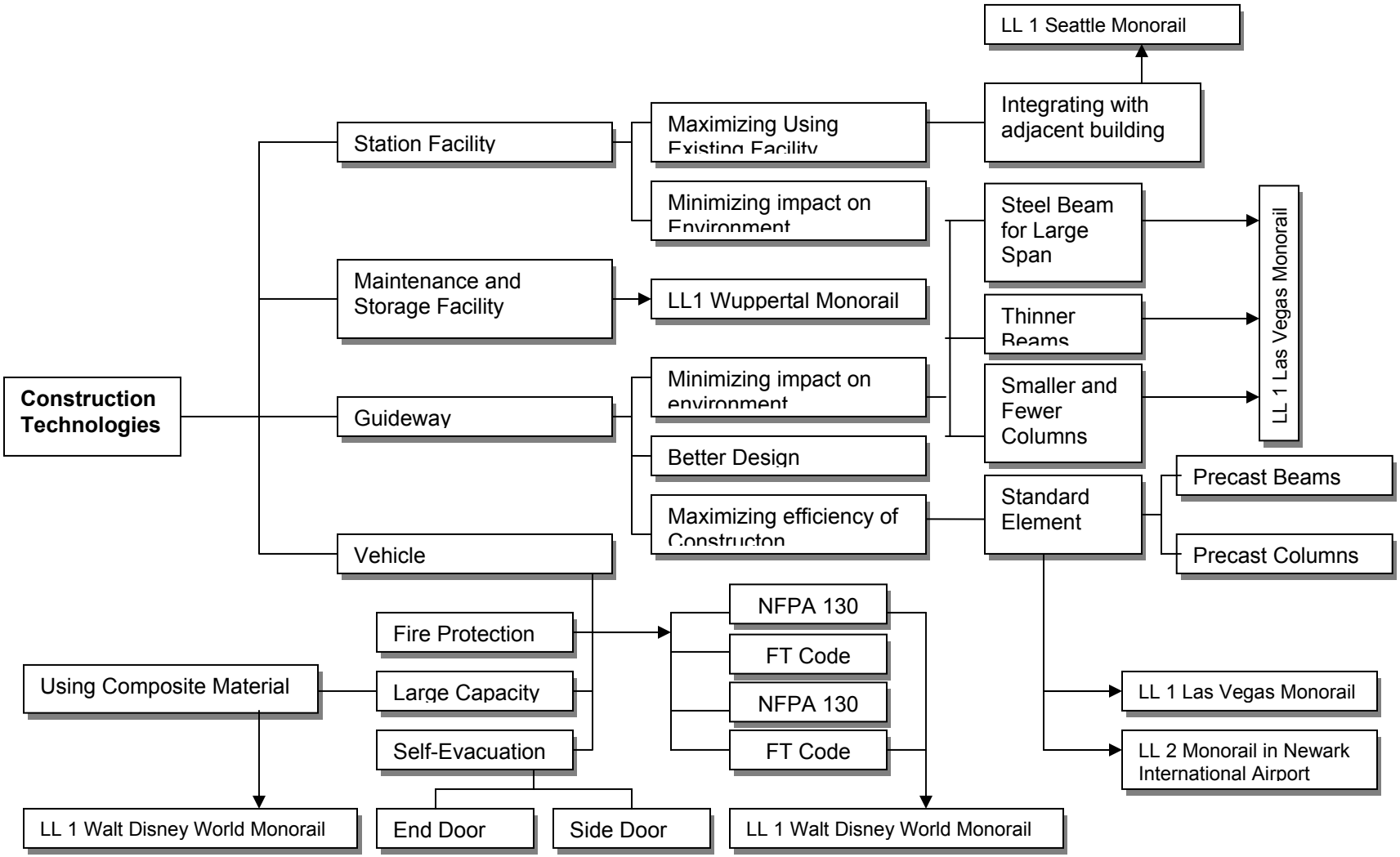

Figure 9 HOT Diagrams of Construction Technologies for Monorail Project

5.3 Case Studies

(1) Precast Elements to Minimizing Impact on Surrounding Utilities

Las Vegas Monorail Project

This design was carried out in approximately six months by a team of engineers from VSL Corporation in San Jose, California. Several different alignments for the guideway structure were considered to minimize impacts on the operation of the hotel, and to minimize the impact on surrounding utilities, while optimizing the structural layout of the guideway.

To accelerate construction and minimize the impact to the surrounding areas, it was decided that most of the structural components would be precast elements to facilitate the erection and provide the tight tolerances required fro the guideway beams. As a result of this decision, all guideway beams, guideway columns, and station beams were precast. The cast-in-place elements were the foundations, caissons, caissons caps, station main columns, and the maintenance facility (Stone 1998).

(2) Guideway Structure

Kitakyushu Monorail Project

Considering the monorail project is located in the central part of the city, engineers used steel beams to minimize the number of pylons so as to not to impair the city appearance. In rainy weather, steel beams tend to cause the rubber tires to slip as their cohesion to the running surfaces of the beams decline. In view of this, steel beams used in section with a gradient of 3% or more were

provided with a grooved upper flange to increase the friction resistance of the upper surface. In this way, the operation safety of the monorail project was ensured (Aoki and Ishikawa, 1989).

Okinawa Monorail Project

In the decision of the guideway structure, experts considered the natural environment in Okinawa and the approach of procurement in this project. For Okinawa is surrounded by water, salty water from ocean damages steel. When they adopt suspension type, they have to import steel from Japan Mainland because Okinawa doesn't have steel manufacturing industries. When they adopt straddle type, local companies can produce concrete and assemble pylons because Okinawa has concrete manufacturing industries. In Okinawa, Suspension type made of steel is more expensive than straddle type. Therefore, the straddle type was adopted in this project. The result has showed that constructability analysis in this project not increased the endurance of the structure, but also saved the transportation cost of the material in the construction phase (Kina and Kuroshima, 1998).

(3) Integrating station and guideway with adjacent facilities

Seattle Monorail Project

The Seattle Planning Commission and Seattle Design Commission are committed to providing constructive advice regarding the planning and design aspects in Seattle Monorail Project. Stations design was suggested as follows.

First, stations should be integrated into adjacent existing facilities to the fullest extent possible, in order to reduce the visual and functional impacts of the large station areas on public streets. At the same time, this method will reduce the cost of stations construction, take advantage of some temporary facilities and speed the construction schedule. Also, the choice of the stations location should consider the connections with other transportation facilities, compatibility with existing roads, future development project, conformity to structural standards etc (SPC 2002).

(4) Construction Activities and Contract Type

Las Vegas Monorail Project

A construction team started to operate in Las Vegas almost at the same time design started. This team coordinated construction activities with the owner, provided the design team with survey information, and worked with local utilities to ensure a timely relocation of those utilities impacted by the monorail layout. The coordination between different participants was critical to the successful commissioning of the monorail (Stone, 1998).

The Las Vegas monorail is using a relatively new approach to building transportation project. A private group of companies is designing and building the project for a fixed price. If the project exceeds its budget, the contractors are liable for additional costs. If the project does not open on schedule, the contractors pay a substantial penalty. In addition, the companies that build the system will operate and maintain it for 15 years with a 99% performance

guarantee. This ensures that the people who build it have a strong financial incentive to build it right and for the long-term. This approach is called Design, Build, Operation and Maintain ------ or DBOM, which provides incentives for the life cycle cost efficiency in design and construction, and stimulate the DBOM team build a high-quality system (Weeks 2002).

6. Constructability Implementation Progress

A constructability program is the application or process of a systematic optimization of the construction-related aspects of a project during the planning, design, procurement, construction, test, and start-up phases by knowledgeable, experienced construction personnel to ensure that the projects are buildable, cost effective, biddable, and maintainable. A corporate and project level constructability implementation program has already been developed by the Construction Industry Institute (CII 1993) (See figure 10). After identifying constructability issues related to the monorail project, in this section, a framework will be developed to improve monorail constructability implementation based on the roadmap in Figure 10. The focus of the developed framework is incorporating construction knowledge, and experience, as early as possible within the project life cycle and capturing that knowledge to pass onto future projects.

Constructability analysis has been implemented in some monorail projects. For example, in Las Vegas Monorail Project, a construction team started operation in Las Vegas almost at the same time design started. This team coordinated construction activities with the Owner, provided the design team with surveying

information, secured building permits, and worked with local utilities to ensure a timely relocation of those utilities impacted by the monorail layout.

However, a systematic and complete constructability analysis hasn't been seen in literature review. From the basic 17 implementation concepts listed in the above and many construction practices of existing monorail projects, we develop the guidelines for monorail project constructability program based on the road map (Figure 10):

1) Monorail Constructability must be addressed at the outset of a project
The project strategy should clearly state the intention to implement a constructability program. Commitment to this strategy by the project team should be enlisted through positive leadership, clear goal setting, effective procedure development, training and support. Key constructability activities events, such as route planning, guideway structure design and traffic management, should be identified and planned into the project program, with a construction manager being appointed early in the project development phase to work with the project definition and design teams to ensure constructability is fully addressed. Reviews should be undertaken early during each key project phase as pro-active events seeking to 'design in' positive ideas, and not as reactive responses attempting to 'design out' weaknesses. It is important to recognize that as with all value management activities, the potential for achieving improved constructability

results is highest at the outset of a project and reduce as the project progresses toward the construction phase.

2) Constructability reviews should involve all relevant participants

Including personnel from planning, design, procurement, construction, commissioning, operations, vendors, and contractors, plus specialist information and service providers, all relevant participants should be included. Construction contractors selected for the project should be assessed on their strengths and weaknesses, their capabilities and competence levels. Contractor strengths should be integrated into design, procurement and construction plans, while awareness of and appropriate allowance for weaknesses should be made. This is only possible if construction contractors are identified and appointed at an early stage of the project. Contractors should be encouraged to participate in the constructability program and contribute to constructability reviews, studies, ideas and initiatives. This will maximize the benefits of contractor expertise, ensure ideas and initiatives are practical, and obtain contractor ownership and commitment within the project team.

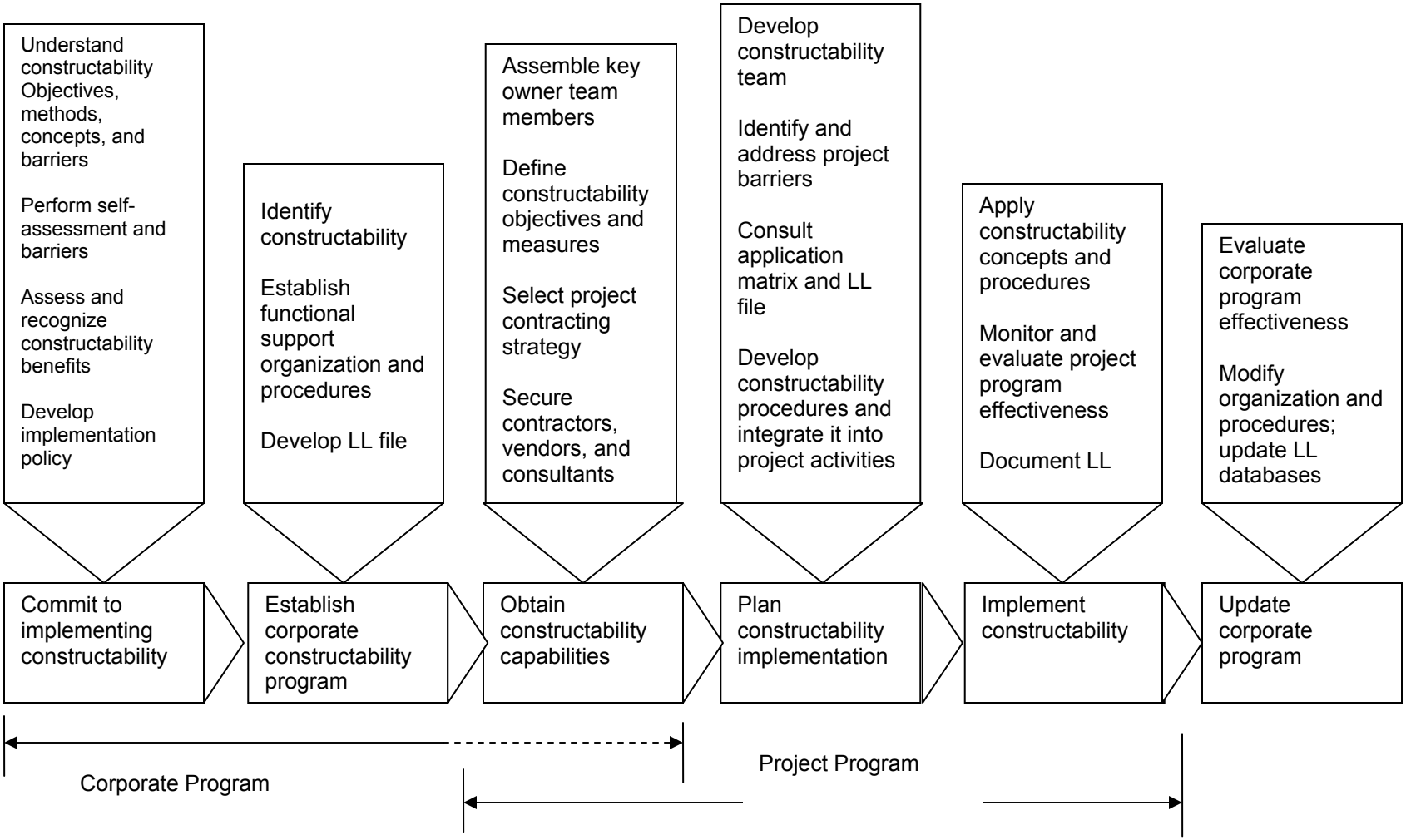

Figure 10 Constructability Implementation Roadmap for Monorail Project

3) Best practice, lessons learned and construction knowledge and experience should be recorded

Best practice, lessons learned, and construction knowledge and experience from previous project constructability initiatives, should be used to optimize the planning, design and construction of the current project. New ideas and innovation should be encouraged, controlled, recorded and assessed in the context of continuous improvement. Specific constructability studies, identified by the project and constructability teams, should be conducted, with the results subsequently assessed for overall project benefit. All relevant constructability ideas generated throughout the project should be recorded and assessed for their contribution to the project. A structured listing of ideas should be developed and reviewed for impact on the project. Ideas found to be of overall project benefit should be acted as constructability initiatives and implemented at the appropriate project phase.

7. Conclusion

Constructability analysis is needed for monorail construction to improve efficiency, enhance safety and reducing cost. A formal constructability program is very beneficial. However, there is not a formal constructability program has been implemented in existing monorail. More research is needed to identify issues and problems in monorail construction. Integration of construction knowledge into planning, design and construction phase as early as possible could optimize the overall project.

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