

Identifying and analyzing interdependencies in the process of urban infrastructure provision

A qualitative multiple embedded case study in Iran

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Abstract

This paper addresses an important aspect of urban infrastructure provision, which is the interdependencies between agencies involved in the process of provision of these critical urban systems. In order to identify these interdependencies, a qualitative multiple embedded case study, comprising the process of urban infrastructure provision for four new residential sites in Iran, was designed and conducted. The unit of analysis was the process of provision of different kinds of urban infrastructure systems, including water supply system, piping gas network, sanitation sewage system, electric power grid, telecommunication network, and transportation system network. The findings indicate that there are various kinds of interdependencies between agencies involved in the process, which can be classified into three main categories, namely, site selection interdependencies, designing interdependencies, and implementation interdependencies. Identifying these interdependencies provides a guide for decision-makers to consider the potentials and limitations of urban infrastructure systems in planning for new housing development areas.

Introduction

In the context of rapid urban growth in developing nations such as Iran, urban infrastructure provision (hereafter, referred to as UI-provision) is of critical importance. That is, in the absence of these critical urban systems, every kind of urban expansion would lead to squatter settlements and slum formation^{1,2}. Urban infrastructure systems are the pillars and the main structure of modern civilized society, providing water supply system, wastewater collection network, electric power grid, telecommunication network, gas piping system, and street network.

Urban infrastructures are defined as a framework of interconnected networks³ and interdependent systems⁴. These two unique features differentiate the process of UI-provision from other kinds of urban development activities. It is obviously irrational to provide a given infrastructure in isolation from other urban infrastructure systems. In other words, the interconnected and interdependent nature of infrastructure raises several interdependencies in the process of UI-provision, such that the success of the process would be jeopardized if these interdependencies were not managed. Moreover, interdependencies in the context of UI-provision can be derived from the fact that all kinds of urban infrastructure systems must be constructed in a limited space (bed of street).

The importance of identifying interdependencies in the context of UI-provision is derived from the fact that by managing these interdependencies, according to ⁵, we can coordinate different agencies involved in the process of UI-provision. It is important to note here that coordination is a major aspect of UI-provision for a new development area⁶. Therefore, this research by analyzing the process of UI-provision for four new residential areas in Iran, aims to identify and analyze the various kinds of interdependencies in the process of UI-provision.

The remaining sections of this paper are structured as follows: research background and statement of the problem are presented in Section 2. In Section 3, the research methodology is introduced. Research findings are described in Section 4, while Section 5 provides a brief discussion on research findings. Finally, concluding remarks are presented in Section 6.

Research background and statement of the problem

Provision of urban infrastructure for a new residential area is a multifaceted process, comprising three main stages, namely, site selection stage, designing stage, and implementation stage⁷. The financing aspect, physical characteristics of a new residential area, and coordination problems are prevalent challenges found in the process of UI-provision⁸. These three major aspects of UI-provision have been investigated from different perspectives.

Physical characteristics of a new residential area, including gradient, elevation, topography, soil type, street pattern, lot size, and density are influential factors in the process of UI-provision. Kain⁸ examines the effects of physical characteristics such as street

pattern, lot size and density on UI-provision cost. According to him, the effects of shape and size of lots are more significant than others. Similarly, ⁹ assess the cost of provision of water supply and wastewater collection network associated with housing patterns in terms of lot size, distance from an existing network, and tract dispersion. Along the same track, DeMers¹⁰ analyzes the relation between Parcel Shape Index (the ratio of the parcel's perimeter over the square root of its area) and UI-provision cost.

Financing aspects are a main concern in the context of the UI-provision¹¹. A large portion of UI-provision related researches has been devoted to this determinant aspect of UI-provision. According to ¹², when UI-provision is subject to user charges, it is more cost-effective. Along the same track, Azizi¹³ introduced direct user-pay system as a financing method was applied in the context of UI-provision in Iran. Azizi¹⁴ evaluated this financing model in terms of social equity and effectiveness. From another point of view, Pethe and Ghokde¹⁵ stress the requisiteness of finding new ways for investment in urban infrastructure development such as "municipal-bonds". In the same vein, Han and Liu¹⁶ examine the effectiveness of new methods of financing such as private equity funds, building up trusts, asset securitization of real estate properties applied in the context of UI-provision in China.

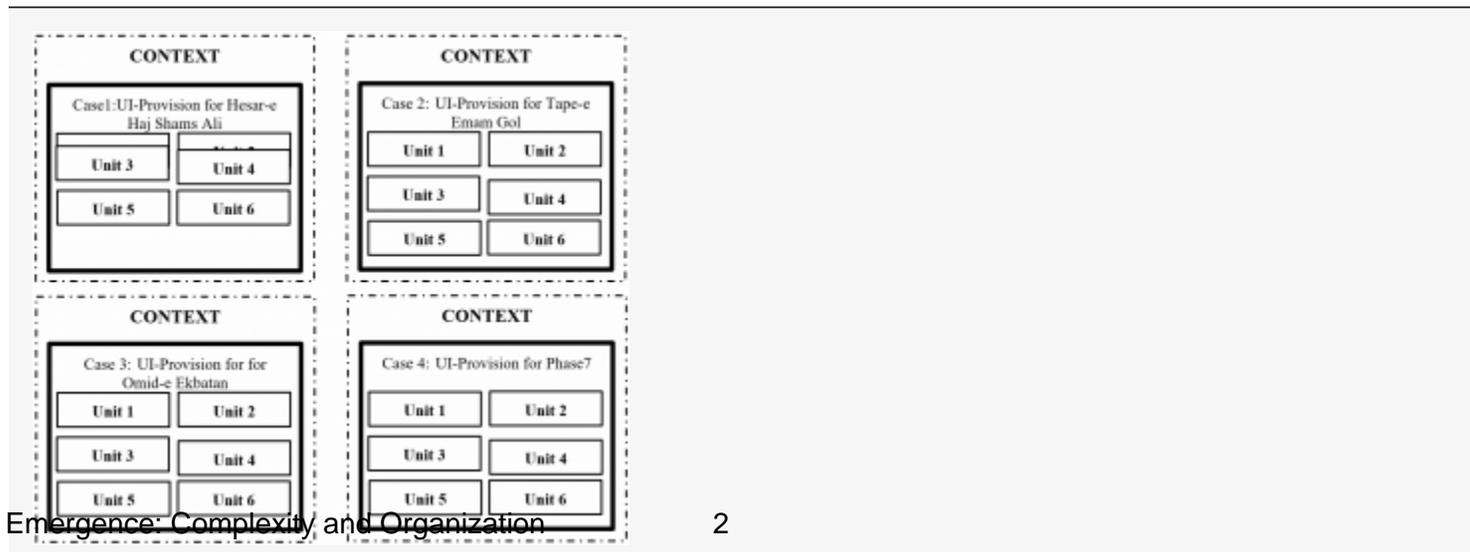
Finally, coordination, or managing interdependencies⁵, plays a vital role in the context of the UI-provision. Liu¹⁷ argues about policy coordination in the process UI-provision in China. In a similar effort, planning and policy coordination in the process of infrastructure provision in Thailand has been analyzed by Webster and Theeratham¹⁸. From another perspective, coordination context of UI-provision in Iran has been scrutinized by ¹⁹.

Coordination, or managing interdependencies between different agencies involved in the UI-provision, brings together these agencies to make their endeavors compatible in the interests of effectiveness and efficiency. In the absence of a mechanism for coordinating these interdependencies, the process of UI-provision results in inefficiency, which occurs when these agencies engage in destructive competition; when spillover over the jurisdiction of agencies could not be managed; when constrained resources are fragmented. However, despite the importance of this pivotal aspect of UI-provision, insufficient attention has been devoted to it. Therefore, the purpose of this research is to identify various kinds of interdependencies between agencies involved in the process of UI-provision.

Research methodology

Considering the aim of this research, which is to identify interdependencies between different agencies involved in UI-provision, it is deemed that qualitative inquiry is an apt approach for collecting, analyzing, and disseminating data. This is because, according to ²⁰, only qualitative approaches are sufficiently sensitive to allow detailed analysis of the process such as UI-provision process. In conformity with this, Denzin and Lincoln²¹ point out that "Qualitative implies an emphasis on processes and meanings that are not rigorously examined, measured, in terms of quantity, amount, intensity, or frequency" (p. 4). Qualitative inquiry is an umbrella term²², covering a variety of forms of inquiry. However, since the phenomena being studied are bounded and contemporary events, according to ²³, among different forms of qualitative approaches, qualitative case study is assumed to be the most appropriate one.

Case study as a research inquiry can be designed and conducted in four general types: single-case holistic design, single-case embedded design, multiple-case holistic design, and multiple-case embedded design²³. Considering the nature of the phenomena being investigated as well as the striking advantages of multiple case over single case^{24,25}, a multiple-case embedded design was designed and conducted. As shown in Figure 1, it comprised the process of UI-provision for four new residential sites in Iran, namely, *Hesar-e Haj Shams Ali* in Hamedan, *Phase 7* in Hashtgerd New City, *Omid-e Ekbatan* in Hamedan, and *Tape-e Emam Gol* in Hamedan. Every case includes six embedded units of analysis: provision of wastewater collection system, provision of gas piping network, provision of electricity network, provision of water supply system, provision of transportation network, and provision of telecommunication network.



Source of data

In this research, data came from three main sources of data in qualitative research, namely, interviews (semi-structured and focus group), documents, and observations. Eliciting data from three different sources would meet the requirements of triangulation²⁶.

Interview. A total of 32 representatives from different agencies involved in the process of UI-provision for the above mentioned new residential sites in Iran were selected. Each semi-structured interview session lasted around one hour and the interviews followed a written interview guide. During interview sessions, some follow-up questions or probes were posed to provide a deeper understanding of the issues. Moreover, in addition to doing interviews, four focus group sessions, involving representatives of the aforementioned agencies, were conducted. Using snowball strategy²⁷ and based on the following criteria, participants for interviews and focus group sessions were selected:

- Job position is related to UI-provision
- The number of years on the job
- Date of participant' s involvement in UI-provision

However, all interviews and focus group sessions, except two interview sessions, were tape recorded and transcribed. The resulting verbatim transcriptions provided a reliable database for the analysis stage.

Documents. Document as a ready-made source of data in combination with two other sources of data, offers a holistic understanding of the phenomenon under study. Since this research aims to identify interdependencies between agencies involved in the process of UI-provision, it is advantageous to seek out the paper trail of what cannot be understood about the interdependencies, things that could not be observed. The process of extracting data of documents in this research was divided into three steps. In the first step, prior to field visit, an extensive internet surfing provided valuable data about the issue. Then, during fieldwork, pertaining documents such as agency archives and records, inter-agency letters, local newspapers, and instruction booklets were reviewed. In the second step, gathered documents were evaluated. In the final step, based on the kinds of interdependency, the evaluated documents were coded.

Observation. Observation, as a main technique of data collection in qualitative inquiry, provides fist-hand data about the issue under study ²⁸. In this research, observation covers physical traces of various kinds of interdependency between organizations involved in the process of UI-provision. It was done during three main stages, namely, entry stage, data collection stage, and existing stage. However, intended observation, taking field notes, photography were three main observation activities in this research.

Data analysis

Data analysis, in this research, comprises abstracting, enhancing, and interpreting what has been said (in interview sessions), what has been seen (in observation), and what has been read (in the documents). The process of data analysis in this research was oriented by "Relying on theoretical proposition", as a general analytic strategy²³. Relying on this general analytic strategy, "explanation building" technique (a special type of pattern matching) was applied to construct categories or findings. Furthermore, in order to improve the trustworthiness of the findings, literal replication in two different levels, cross and within cases, was done.

The process of construction of categories (findings), in this research, began with "open-coding"²⁹ in which the process was as open as possible to embrace any piece of data that might be significant in the construction of categories. As the process proceeded, it became "analytic-coding" or "axial-coding"³⁰ where coding notes were classified into some tentative categories. Then, these tentative categories were revised so that the categories that could not stand across more than one set of data became sub-categories or were omitted. However, the process of the category construction in this research moves from highly inductive (at the outset of the process) to slightly deductive (at the end of the process).

Validity and reliability issues

In order to enhance validity and reliability of the research findings, several strategies were applied. First, in order to enhance

internal validity, “Member Checking” and “Triangulation” were utilized. Second, “Maximum Variation” strategy was applied to improve external validity. Third, in order to improve construct validity, “Reviewing the Initial Findings by Key Informants” and “Use of Multiple Sources of Data” were applied. Finally, “Triangulation Strategy” was applied to improve reliability of the findings.

Research findings

By analyzing the process of UI-provision in four new residential sites in Iran, this research identified different kinds of interdependency between agencies involved in the process. According to³¹, dependency-focused analysis and activity-focused analysis are two general heuristic approaches for identifying interdependencies. In this research, with respect to the nature of the phenomenon being studied, the former approach was applied. Moreover, in accordance with Adler’s³² interdependency management phases, we divided the process of UI-provision for a new residential area into three distinct stages: site selection stage, designing stage, and implementation stage. However, the findings are summarized below.

Site selection interdependencies

Process of site selection for a new residential site would be successful if in addition to considering basic criteria (such as zoning considerations, community acceptance, acquisition or lease costs, etc.), limitations and potentials of urban infrastructure agencies are also considered. These limitations and potentials present themselves in the forms of interdependencies between agencies involved in the process of UI-provision for a new residential area. These interdependencies are as follows:

Capacity Interdependency. There is a finite capacity for all kinds of urban infrastructure systems. When an additional demand is loaded on one infrastructure, a portion of the capacity would be allocated to it. If a new demand exceeds the original capacity, stoppage in the system occurs³³. Lack of attention to the available capacity of infrastructure systems during the site selection for a new residential area results in operational problems during the life-cycle of these critical urban systems.

Legal Issues Interdependency. During the site selection stage, there are several types of legal interdependencies between agencies involved in the UI-provision. For example, “Right-of-way” and “access issues” are two influential legal interdependencies which if not respected in the site selection stage, will result in several problems in the implementation stage. By definition, right-of-way is a type of easement over the land usually for transportation purposes, but it could be used for the passing of other urban infrastructure elements such as water transmission lines, electrical transmission lines, and so on.

Safety-Distance Interdependency. With respect to the nature of urban infrastructure systems, there is a safety-distance for each kind of these fundamental urban systems. The necessity to consider infrastructure safety-distance during site selection stage triggers an interdependency between agencies involved in the UI-provision, such that, if this interdependency could not be managed, several problems emerge in the future operation of the urban infrastructure systems.

Relative Location Interdependency. Location of a new residential site in relation to extant urban infrastructure systems, in terms of vertical or horizontal distance, is an influential factor for the success of UI-provision process. That is, the capacity of urban infrastructure is locationally fixed and available for a limited geographic territory³³. This feature of urban infrastructure systems results in a kind of interdependency, which we will call “relative location interdependency”. If this interdependency is not considered during the site selection stage, the process of UI-provision would be faced with numerous implementation problems.

Designing interdependencies

During the designing stage of UI-provision for a new residential site, there are several kinds of interdependencies between agencies involved in the process. If these interdependencies could not be managed in this stage, several coordination challenges would emerge in the implementation stage. The following research findings illustrate different kinds of interdependencies between agencies involved in the designing stage of UI-provision.

Demand information interdependency. An important element in the designing stage of UI-provision is information about the volume and type of demand for these critical systems. That is, in the absence of information about other agencies’ requirements and plans, the designing process certainly results in shortcomings such as failures in meeting demands, lock-in for citizens due to inadequate infrastructure systems, and discord and friction between agencies involved in the process. Furthermore, in addition to demand-supply relation between urban infrastructure providers and gainers, the mutual interdependency between these critical systems triggers the same relation between urban infrastructure agencies (UIAs) during the designing stage.

Technical Information Interdependency. The interconnected and interdependent nature of urban infrastructure systems³⁴ lead to a situation in which technical information about one system is a key element in the designing process of other urban infrastructure systems. Furthermore, since there is one common limited space (bed of street) for implementation of all kinds of urban infrastructure systems, technical information of a given system plays a vital role in the designing process of others. Therefore, it is clearly impossible to successfully design a given infrastructure in the absence of technical information about other urban infrastructure systems.

Requisite Interdependency. Urban infrastructures are mutually interdependent systems such that there is a bidirectional relation between the states of any given pair. The bidirectional relation between these systems produces a designing environment in which the designing process of a given system is influenced by inputs and outputs of other systems. This special designing environment implies an interdependency between the designing process of these critical systems which we call "Requisite Interdependency". Requisite Interdependency refers to a bidirectional or multidirectional interdependency between urban infrastructure systems such that the characteristics of the outputs of one system must satisfy the required features of the input of other systems.

Implementation interdependencies

During the implementation stage of UI-provision, urban infrastructure plans are put into motion and their execution works are performed. The interconnected and interdependent nature of urban infrastructure system as well as the existence of a limited space for construction of all of them result in the importance of identifying and managing various kinds of interdependencies between agencies involved in the implementation stage of UI-provision. These interdependencies are as described below.

Timing Interdependency. Timing interdependency implies a chronological order between implementation of various kinds of urban infrastructure systems such that construction activities of one system must be completed before other construction processes can be started. For example, roadbed must be constructed before the construction process of other urban infrastructure systems can be started. On the other hand, street pavement must be done after other urban infrastructures are installed.

Location Interdependency. This kind of interdependency derived from the fact all kinds of urban infrastructure systems must be implemented in a limited construction space, bed of the street. In the other words, since their elements must be located in closed spatial proximity, urban infrastructure systems are interdependent in terms of their relative locations. That is, the location of one urban infrastructure can affect the implementation process of others.

Resource Interdependency. This kind of interdependency refers to a situation in which a resource is shared between two or more agencies involved in UI-provision. In Iran, for instance, public resource as a main financial resource for urban infrastructure investment is shared between agencies involved in the process of UI-provision.

Technical Information Interdependency. Technical info. interdependency is one of the most prevalent interdependencies during the implementation stage of UI-provision. For example, since street networks are the common bed for all kinds of urban infrastructure systems, technical information about street elements such as the street elevation and street-side line play a vital role in the successful implementation of other systems. For the same reason, as-built information of one infrastructure is an important factor in the proper implementation of other urban infrastructures.

Input- Output Interdependency. This interdependency implies a relation between urban infrastructure systems in which the state one system is dependent on the outputs of other systems. This kind of interdependency, as the term implies, derived from an input-output link between a given pair of urban infrastructure agencies. For instance, electric power, an output of the Electric Company, is a required input for normal operation of water supply system.

Administrative Interdependency. Organizational linkages and laws and regulations govern the process of urban infrastructure development, in Iran, stimulate a kind of interdependency between agencies involved in UI-provision called, in this research, administrative interdependency. For example, laws associated with the safety distances between elements of different kinds of urban infrastructures, such as Iranian Gas Standard (IGS), trigger this kind of interdependency in the context of UI-provision.

Discussion

We intentionally use the term interdependency rather than dependency to address interrelations between agencies involved in the process of UI-provision for a new residential site. This is because, according to³⁵, there is a bidirectional relationship between a given pair of agencies who are engaged in the context of the UI-provision. The importance of identifying and understanding interdependencies is derived from the fact that coordination (one of the triple major aspects of UI-provision) is nothing more than managing interdependencies between actors and activities⁵. In order to identify these interdependencies, the processes of UI-provision for four new residential sites in Iran, using the dependency-focus approach, were analyzed. As illustrated in table 1, various kinds of interdependencies between agencies involved in the process can be classified under three main stages of UI-provision for a new development area, namely, site selection stage, designing stage, and implementation

Table 1.

Various kinds of interdependency between agencies involved in UI-provision for a new Residential area		
Stage	Interdependency	
Site Selection Stage	– Capacity Interdependency- Legal Issues interdependency- Safety-Distance Interdependency- Relative Location Interdependency	
Designing Stage	– Demand information interdependency- Technical Information Interdependency- Requisite Interdependency	
Implementation Stage	Timing Interdependency- Location Interdependency- Resource Interdependency- Technical Information Interdependency- Input-Output Interdependency- Administrative Interdependency	

These interdependencies are directly or indirectly derived from three main origins: the interconnected and interdependent nature of urban infrastructure systems, existence of a limited space for implementation of all urban infrastructure systems, and administrative policies governing the process of UI-provision. Although each interdependency has its own characteristics, distinct from other kinds of interdependency, these classifications of interdependencies are not mutually exclusive. For instance, in spite of fact that location interdependency and timing interdependency are totally different in terms of their characteristics, they directly and indirectly influence the state of each other. However, interdependencies between agencies involved in the UI-provision vary vastly and each interdependency can influence the overall outcomes of the process.

Conclusion

Coordination, or managing interdependencies, is an important aspect of the process of UI-provision, that is, it brings together involved agencies to make their efforts more compatible in terms of efficiency and effectiveness. Therefore, it is mandatory to identify, understand, and manage different kinds of interdependency between independent agencies involved in the process of UI-provision for a new residential area. In this research, by analyzing the process of UI-provision in Iran, we identify these interdependencies during the three main stages of the process, namely, site selection interdependencies, designing interdependencies, and implementation interdependencies. Identifying these interdependencies provides a guide for decision-makers to consider the potentials and limitations of urban infrastructure systems in planning for new housing development areas. In future work, we will present an agent-based coordination framework for managing these interdependencies.

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