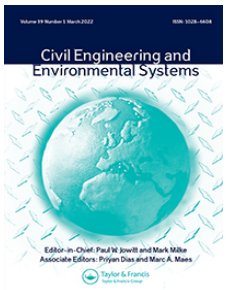

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RESEARCH ARTICLE

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Local public right of way for surface and subsurface resource integration

Terri Matthews[a] and Debra F. Laefer[b]

[a]Civil Engineering Department, NYU/Tandon School of Engineering, Brooklyn, New York; [b]Civil Engineering Department and Center for Urban Science and Progress, NYU/Tandon School of Engineering, Brooklyn, New York

ABSTRACT

A utilidor is a 'system of systems' infrastructural solution to the 'subsurface spaghetti' problem resulting from direct burial of utility transmission infrastructure beneath the public right of way (PROW). The transition from direct burial to utilidors in older, dense American cities has generally not occurred, despite the potential to increase system performance in a long-term, financially and environmentally sustainable manner, because it would require reform of local planning practices and of utility pricing to support financing within a complex regulatory system. Utilidor adoption in New York City (NYC) would be a significant local infrastructure transition, amplifying the need for locality-based research, that would occur while each utility sector undergoes its own infrastructure transitions, thereby increasing the level of regulatory complexity. This paper applies transitions analysis, recursive collective action theory, and capacity to act analysis to NYC's experience with its PROW subsurface spaghetti problem and utilidor implementation to demonstrate a place-based methodology that identifies specific sources of resistance to innovative subsurface design and feasible pathways for resolving them. This methodology would be transferable for application to other American cities or classes of American cities to supplement the limits of generalised subsurface and subsurface resource integration research for practitioner application.

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Utilidor; infrastructure transition; capacity to act; Transitions analysis; Recursive collective action; subsurface planning

1. Introduction

There is a reciprocal relationship between the surface and the subsurface with private and public utilities supporting the economic vitality of urban areas (Kahn 1988; Bertaud 2018). Cities are economic engines for jobs and workforce creating high residential and commercial building densities (Bertaud 2018) leading to more utility customers and higher utility revenues, as compared to less dense jurisdictions within the utilities' service areas. The higher concentration of economic production and consumption in cities increases surface and subsurface densities within established jurisdictional boundaries (Hodson et al. 2012), with greater demand for utility services and resulting increased subsurface transmission infrastructure. Direct burial of utility transmission infrastructure beneath

CONTACT T. Matthews tcm2001@nyu.edu
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the public right of way (PROW) results in increased subsurface infrastructure density. The costs and operational difficulties of street excavations required by direct burial leads to insufficient levels of utilities' state of good repair (SOGR) activities for this infrastructure, including regular inspection, maintenance, repair, rehabilitation or replacement, which results in predictable infrastructure failures (Sterling and Nelson 2013, 44–45; Dunlap 2015). Utility service provision and subsurface infrastructure SOGR activities are critical components of this reciprocal surface-subsurface relationship, which forms the basis for the local planning and financing activities necessary for a transition from direct burial to utilidors to achieve surface and subsurface resource integration.

Municipalities have the potential to innovate 'to reconcile economic growth, wellbeing and the sustainable use of resources' (Hodson et al. 2012, 789), but a municipality's ability to unlock its potential to innovate depends on its legal capacity to act as a jurisdiction (Hammer 2009, 8–14). Each state in the United States (US) creates its local governmental units and grants them specific powers that serve as constraints on their capacity to act on particular issue areas. Thoroughly understanding a municipality's legal capacity to act with respect to a local subsurface infrastructure is critical, because planning and finance are primarily local government functions (von der Tann et al. 2020; Sterling and Nelson 2013; Reynolds 2019). Since the cost of construction and maintenance of publicly- and privately-owned subsurface PROW infrastructure represents significant portions of public and private utility capital budgets (Hodson et al. 2012, 790), unlocking the potential for direct savings through innovation also requires understanding utility regulation as it relates to finance.

Utilidors—or multi-utility tunnels—are transitable, linear, subsurface pieces of infrastructure containing public and private utility transmission infrastructure that safely segregate and protect the infrastructure located within them (Garcia and Berrade 2009, 119) and can increase the efficiency of subsurface PROW space use. Utilidors are mixed public-private assets that represent a financially and environmentally sustainable 'system of systems' solution to the well-documented 'subsurface spaghetti problem' created by direct burial (Canto-Perello, Curiel-Esparza, and Calvo 2006, 1; Sterling and Nelson 2013; Curiel-Esparza, Canto-Perello, and Calvo 2004; Admiraal and Cornaro 2016; von der Tann et al. 2020). Utilidors both insulate transmission lines from subsurface conditions and from each other (Hunt, Nash, and Rogers 2014) (Figure 1). Direct burial of transmission infrastructure exposes it to the risks of degrading subsurface conditions, adverse impacts from other utility commodities, and accidental strikes from excavations (Luo et al. 2020, 1; Canto-Perello and Curiel-Esparza 2013, 2; Makana 2014). Utilidors designed for each utility commodity's physical needs largely eliminate these risks with the added benefit of facilitating easier and cheaper access for individual utility SOGR activities with minimal, if any, street excavation (Luo et al. 2020, 1; Canto-Perello and Curiel-Esparza 2013, 2–3; ASCE 2021), resulting in improved infrastructure asset conditions with reductions in predictable failures and related injury and property damage (Luo et al. 2020, 1–3; Canto-Perello and Curiel-Esparza 2013, 2–3; ASCE 2021). Repeated utility excavations and restorations contribute to surface PROW condition degradation and associated temporary street closures and exacerbating surface PROW congestion (Luo et al. 2020, 1; Canto-Perello and Curiel-Esparza 2013, 2–3; ASCE 2021). Eliminating street excavations would significantly extend roadway design life (Curiel-Esparza and Canto-Perello 2012), as well as decrease construction-induced traffic congestion and

Figure 1. Image of a utilidor in practice in the United States.

affiliated construction demolition waste. Finally, utilidors can also enable the application of integrated computer technology (ICT) into transmission infrastructure and the creation of operational systems for continuous, real-time, remote monitoring. The potential for such control of utility infrastructure assets and commodity conditions would drive greater direct 'smart city' savings through computer data driven SOGR activities and earlier incident response capacity (Luo et al. 2020, 28; Sterling and Nelson 2013, 54; Hall et al. 2000; Britton, Stewart, and O'Halloran 2013; Metje et al. 2011).

Despite these many benefits, a recent survey of utilidor implementation revealed that utilidor systems in the US exist primarily on privately-owned institutional properties and generally exclude public water and sewer infrastructure (Luo et al. 2020, 2, 21, 29; see also the previously published APWA 1971). These findings may be partly due to a utilidor's higher initial costs, compared to direct burial (estimated to be at least twice direct burial costs), and the legal and operational challenges of new, mixed, public-private assets (Canto-Perello and Curiel-Esparza 2013, 3; Luo et al. 2020, 2, 21, 29).

Utilidors have historical antecedents dating back to ancient Rome (Garcia and Berrade 2009, 119). While there are examples of utilidors in modern, dense, urban areas (Luo et al. 2020; Bugher 1970; APWA 1971), the conditions of their creation are sufficiently distinct from those in present-day New York City (NYC) that they cannot serve as direct precedents. A prominent example is Paris's sewer system, with its nineteenth century military roots (Bugher 1970, 299; see also Gérard and Nguyên 2005), which eventually became a series of utilidors. Similarly, Bazalgette's nineteenth century construction of London's sewer system included 'pipe subways' where feasible (Smith 1986, 99). Both these examples occurred during or shortly after system inception when the 'master planner-engineer-builder' existed. London's use of the 'pipe subway' continues today as

opportunities present themselves, but NYC has never followed this approach. Subsequently, Spain's first modern utilidor debuted in Madrid in 1952, justified by the long-term economic value despite unfavourable economic conditions (Bugher 1970, 299). Despite these prominent examples, such efforts have not been implemented in NYC, in part due to NYC's multiple, financial crises over the past half century (as discussed below). This is despite the putative long-term economic benefits of utilidors.

The subsurface spaghetti problem resulting from NYC's failure to plan for the subsurface PROW is revealed in open street pits (Figure 2) for roadway reconstruction projects, which occur when NYC Department of Environmental Protection (DEP) water and sewer main and catchment infrastructure replacement projects and NYC Department of Transportation (DOT) surface roadway reconstruction projects coincide in time and location and become consolidated as NYC Department of Design and Construction (DDC) roadway reconstruction design and construction projects. These projects represent good candidates for utilidor implementation.

Utilidors hold the potential to resolve subsurface spaghetti and surface PROW problems. However, implementation at the municipal level requires highly localised knowledge, because generalised knowledge has proven insufficient for local action (Tabory et al. n.d.; Tabory and Ramaswami 2020). Practitioners in complex, urban jurisdictions dismiss generalised research unconnected to embedded practices and local government processes as inapplicable to local conditions (for example, AASHTO 1996 focuses on a single type of utility service; AASHTO 2005 focuses on highway right of way). So, while there is extensive literature on utilidors and the benefits of integrating subsurface and surface resources to

Figure 2. 40 Worth Street, NYC, roadway reconstruction project, November 2021.

solve environmental sustainability and resiliency problems, such research has not explored local implementation impediments (Coenen, Benneworth, and Truffer 2012). These impediments include significant local planning reform and regulatory reform to support innovative financing, both of which are complicated efforts. Initiatives to support subsurface and surface integration within the PROW are further complicated because this integration is essentially an overarching or meta infrastructure transition (the meta-transition) taking place, while all utility sectors are simultaneously undergoing their own systemic infrastructure transitions (Hodson et al. 2012; Coenen, Benneworth, and Truffer 2012, 796). The nature of this meta-transition crossing all sectors increases the level of implementation complexity and amplifies the need for locality-based research and analysis (Tabory et al. n.d.; Tabory and Ramaswami 2020; Coenen, Benneworth, and Truffer 2012).

Researchers must understand the specific governmental processes that pose constraints to a local meta-transition, including planning, capital budgeting and finance powers and processes, and public service commission regulation of private utilities. Surface and subsurface resource integration literature recommends urban, subsurface planning activities beyond current technically oriented and project-specific subsurface planning that rarely intersects with official surface planning processes (von der Tann et al. 2020; Sterling and Nelson 2013; Reynolds 2019). Knowledge about the 'engine room of the city' is locked within the engineering profession (Hooimeijer and Maring 2018, 2), and while multi-disciplinary approaches may be increasing in academia, they rarely exist among practitioners (Curiel-Esparza, Canto-Perello, and Calvo 2004, 527). There are 'too few trained professionals for future needs in complex system management' and a 'general lack of attention to utility systems in urban planning processes and within the planning profession' (Sterling and Nelson 2013, 53). Planning reform, though important, would be insufficient to achieve the meta-transition and must be linked to simultaneous related reforms in finance and utility regulation. To illustrate these issues, this paper explores the challenges and opportunities for local utilidor implementation through a case study methodology that leverages NYC practitioner efforts (Town + Gown:NYC 2020-2021) to provide a methodological foundation for a place-based framework, which could be applied to classes of jurisdictions (Tabory and Ramaswami 2020) to identify recurring sources of impediments to surface and subsurface resource integration and provide realistic solutions (initially identified in generalised research) that are based on a specific local authority to resolve these impediments to subsurface infrastructure innovation and technological change in the face of documented benefits.

2. Materials and methodology

This NYC utilidor case study consists of a methodology that (1) applies the transitions analysis framework to NYC's subsurface infrastructure history to identify systemic impediments to infrastructure innovation; (2) analyzes identified impediments in the context of recursive collective action theory; and (3) performs a detailed statutory-based capacity to act analysis. This methodology is intended to provide insights into impediments to the meta-transition as a form of surface and subsurface resource integration and to identify governmental and political pathways necessary for action within and upon the existing sociotechnical and regulatory environment to effect change. (Coenen, Benneworth, and Truffer 2012) While technical engineering, planning and financial analyses of utilidor

implementation are critical, less technical socio-political analyses are pre-conditions to these analyses, because without understanding and identifying routes to solving the socio-political impediments within which utilidor implementation must proceed, there will be no implementation.

Since the utilidor solution provides a series of quantifiable, direct-cost benefits to utilities and the corresponding municipality, NYC practitioner efforts (Town + Gown:NYC 2020-2021) include a proto-project-level, life-cycle, cost-benefit analysis (LCCBA) that, to date, suggests the benefits of NYC utilidor implementation would exceed costs; this is one pre-condition to the meta-transition. Comprehensive, economic-based, LCCBA modelling for utilidor implementation would first evaluate costs and benefits of a utilidor, as a project, and then focus on costs and benefits among utility participants in a way that balances risk, cost–benefit ratios, and contributed versus gained benefits. LCCBA modelling must also permit assessment of a municipality's dual role as owner of the PROW and as owner of a subset of the utilities themselves, for which costs and benefits are similar to those of private utilities (Alaghbandrad and Hammad 2020; see also Canto-Perello and Curiel-Esparza 2016 and Curiel-Esparza and Canto-Perello 2012). NYC practitioner efforts (Town + Gown:NYC 2020-2021) with a proto-LCCBA strongly suggest, however, that even a positive LCCBA will be insufficient for the meta-transition.

A positive LCCBA, economic analyses must translate the meta-transition's benefits to the local and regional economies, which is necessary for public policy justification to generate 'broad bipartisan political, business, labour, and community support,' in places like NYC that have 'fractious political environments' (Admiraal and Cornaro 2016, 222; see also Kahn 2988, II:49–54; Smith, Stirling, and Berkhout 2005, 1503–1504) because a meta-transition will require a governmental-led regulatory reform of planning and utility pricing to support innovative finance within resource-constrained capital programs. Broader economic analyses will help counter the urban PROW practitioners' experience of subsurface spaghetti problems as exogenous and uncontrollable impediments to overcome while they conduct capital projects for SOGR activities and implementing mobility, safety and congestion policies (e.g. Fitzsimmons 2018; BQX 2018, 53). Researchers must also explicitly address constraints imposed by embedded regulatory practices (Egyedi and Sprico 2011, 947; Smith, Stirling, and Berkhout 2005) and acknowledge local *government* and *politics*, which are not the same as the 'governance' concept that elides politics, because the subsurface PROW and its infrastructure are essentially political, and '[a]ll politics is local' (O'Neill 1994, xv; see also Smith, Stirling, and Berkhout 2005).

2.1 Transitions analysis

Transitions analysis (TA) is a three-level analytic framework to understand '"system innovation" in sociotechnical systems such as infrastructure networks' consisting of (1) landscape, (2) regime, and (3) niche levels (Hodson et al. 2012, 794; citing to Geels 2002). TA provides the first step toward contextualizing the meta-transition to identify systemic impediments to infrastructure innovation and pathways for change to support the meta-transition (Hodson et al. 2012, 794; Egyedi and Sprico 2011; Smith, Stirling, and Berkhout 2005; Coenen, Benneworth, and Truffer 2012). The first level is a broad, external, macro-level landscape consisting of 'political cultures, economic growth, macroeconomic trends, land use, utility infrastructures' that exert pressure for infrastructure transition upon the

second level where the municipality operates (Hodson et al. 2012, 794). This middle level is a sociotechnical regime in which the potential for municipal innovation resides (Hodson et al. 2012, 794). Stakeholder interrelationships within this sociotechnical regime reflect 'regulations, policy priorities, consumption patterns, and investment decisions' that not only stabilise the regime but also limit innovative responses (Hodson et al. 2012, 794), because this stabilisation function institutionalises and entrenches existing practices, processes, and relationships within a complex and fractured regulatory environment (Egyedi and Sprico 2011, 947; Smith, Stirling, and Berkhout 2005). The last micro-level niche consists of 'small networks of actors learning about new and novel technologies and their uses' that 'agitate' to get innovations on the regime's agenda (Hodson et al. 2012, 794). Applying the TA framework to the history of a jurisdiction's sociotechnical regime provides insights into the regime's embedded practices that constrain innovation and identifies local impediments to innovation that the jurisdiction could solve (Hodson et al. 2012; Coenen, Benneworth, and Truffer 2012; Egyedi and Sprico 2011).

2.2 Recursive collective action theory

Recursive collective action (RCA) theory frames a particular sociotechnical regime's obduracy in economic and political terms and highlights the governmental action necessary for the meta-transition (Hockett 2015; compare to Jenkins-Smith 1990, 103). An RCA problem exists when multiple individually rational economic decisions yield collectively irrational economic outcomes due to the lack of effective coordination that allows these decisions to continue and compound with increasingly iterative negative impacts (Hockett 2015, 3, 5–6). The aggregation of these individually rational decisions, which exist within a sociotechnical regime, creates 'collectively self-defeating or even self-worsening outcomes' that only 'the presence of a collective agent empowered to act on behalf of all parties to optimize joint outcomes' can change (Hockett 2015, 2). In many issue areas, government is the only actor with authority to act on behalf of the stakeholder group to transform the regime by changing the 'calculus' of each individual actor so that current economic rational decisions leading to irrational outcomes 'cease to be individually rational.' (Hockett 2015, 24; Webster 1914, 201; Smith, Stirling, and Berkhout 2005; Coenen, Benneworth, and Truffer 2012),

2.3 Capacity to act analysis

After applying TA to a particular context and its history to highlight specific regime-imposed impediments to innovation (Coenen, Benneworth, and Truffer 2012, 969) and after viewing these impediments through the lens of RCA to make clearer the nature of the actor necessary to change the regime so that its individual public and private actors can innovate and create a more rationally economic system, the final step is analysis of the jurisdiction's specific legal capacity to act on the regime. Analysis of a jurisdiction's '"capacity to act" or capability to form and implement policy and programs on different matters' is key to evaluating its ability to accomplish initiatives across a variety of issue areas, especially those involving urban energy systems with 'interlinked networks of formal and informal institutions (including energy markets and regulatory systems), technologies, and stakeholders that influence policies, technology decisions

and supply and demand choices for different forms of energy within a city or urban region' (Hammer 2009, 2) In the US, state laws establish all local governments and grant them powers, which can be broad in some areas and narrow in others (Hammer 2009, 2). These constrain their capacity to act (CTA). Pre-emptive federal laws, not examined in this case study, further constrain states and, thus, their local governments.

3. Results

The following section summarises the results of applying the case study methodology to the NYC meta-transition, identifying impediments and potential pathways.

3.1 TA: NYC

Direct subsurface burial of utility transmission infrastructure beneath NYC's PROW began in the eighteenth century with its earliest water and sewer transmission services and was eventually expanded to include gas, electricity, steam, and telecommunication technologies [Garcia and Berrade 2009, 119; Webster 1914, 201; Hausman 1991a and 1991b; Israel 1991; Smith 1991; Bradley 1991]. While water, sewer and gas were always underground, burying electricity and telephony transmission lines only began in parts of NYC after the blizzard of 1888 ifor above-ground transmission wires in locales with high surface densities (Seyfried 1991). Then, direct burial represented a technical improvement over above-ground placement. While not all NYC electric and telecommunications transmission infrastructure is buried (OLTPS), the treatment of transmission lines for subsequent telecommunications technology across NYC has generally followed the earlier patterns established by electricity and telephony.

NYC's public and private utility system is the cumulative result of the historical utility development discussed above that is similar to that of many large US cities**.** NYC, through DEP, provides water, stormwater, and sewer services for all of NYC's five boroughs (Manhattan, The Bronx, Queens, Brooklyn, and Staten Island). Consolidated Edison (ConEd) provides gas to Manhattan and The Bronx, and National Grid provides gas to the rest of NYC. ConEd also provides electricity to the remainder of NYC, except for the neighborhood of Far Rockaways, Queens, which is served by the Long Island Power Authority. ConEd also provides steam heat to parts of Manhattan, which is supplemented by small amounts generated and delivered by the NYC Transit Authority from its operations. Verizon and several other telecommunication companies provide voice, broadband, and cable TV to all boroughs through either the Empire City Subway (ECS) conduit or other conduits. Various other companies similarly provide mobile communications and data transmission services to businesses also through ECS or other conduits.

NYC's subsurface PROW and utility history demonstrates the tenacious obduracy of its sociotechnical regime. The regime's linkage of construction technology and finance began with the early nineteenth century appearance of NYC's subsurface spaghetti problem. Typically, each new utility installed its mains in the utility ditches of other utilities to reduce their initial installation costs (Goldman 1997, 70–71), which they financed on a per utility basis with traditional debt. Later, during early twentieth century subway construction, 'politics' prevented implementation of utility 'pipe subways' (Makana, 2014, 104) alongside the subway tubes, which reveals the political power of road

excavation contractors, whose business would have been reduced and who would be a losing stakeholder in utilidor implementation (Webster 1914, 201; see also Kelly 2022). In the late 1970s, NYC's Mayor's Office of Management and Budget (OMB) rejected a proposal by DEP for a coherent system of subsurface utility separation for several major roadway reconstruction projects. Justification for the decision was based on financial grounds, because NYC's financial resources and market access were constrained as a result of the 1975 Fiscal Crisis. (Francis X. McArdle, first DEP Commissioner (personal communication, April 3, 2021); Fuchs). Similarly, in 2006, NYC's post-9/11 budget constraints precluded a pair of niche-level proposals for targeted pilot utilidor implementation as a cost-effective solution to NYC's subsurface spaghetti problem (Edison 2006; Olympic Associates Company 2006). Most recently,, in 2013, a financial feasibility study for burying overhead utility transmission lines to reduce storm-induced power outages reflected the NYC sociotechnical regime's embedded practices with an unrealistic scope, reliance on extracted data from a prior system-wide Con Edison analysis, failure to consider social costs, and inclusion of costs that utilidors would mitigate (OLTPS 2013, 5, 7; App. A., p. 1; NYC Council LL 13/2013), thereby predisposing a negative outcome.

Official NYC planning activities for private property started around the turn of the twentieth century (Kwartler 1991; see also Spann 1991) and led to increased, local, surface densities and intensified, subsurface, PROW densities to supply utility commodities for NYC's planned development. A practical deference to utility franchises that NYC had granted, however, most likely kept official planning activities from including the subsurface to address the inevitable subsurface PROW congestion. NYC granted franchises (some with 'in perpetuity' terms) under a variety of then-existing legal authorities including common law court decisions, state legislative charters, and state and local laws (Phillips, Jr 1985, 110, 112–113; NYS Transportation Corporations Law). Furthermore, franchises are protected by the 'contracts clause' of the US Constitution, which prohibits public franchisors from revising franchise terms unilaterally to reflect changing conditions, which generally strengthens the regime's obduracy and makes franchise reform as a route for pricing to support utilidor finance virtually impossible (Phillips, Jr 1985, 113–114). Beginning in the early twentieth century, the inability of local utility franchising to adapt 'to the development of an industrialized and highly complex society' led to creation of state utility regulatory commissions across the U.S. (Phillips, Jr 1985, 115–119)

NYC's franchises assume direct burial method as standard operating procedures and do not address problems emanating from the subsurface spaghetti problem or subsurface PROW densities. Specifically, NYC's franchises were never priced to properly account for (1) the subsurface PROW as a limited resource with inherent value to both NYC and utilities operating in NYC through increased utilities' revenues generated in NYC (the subsurface PROW value), or (2) the negative externality costs that NYC and its taxpayers bear from street excavations required for installation, maintenance and repair, the subsurface spaghetti problem, and the lack of subsurface infrastructure location data (the negative direct burial externality costs). The relationship between NYC's increased surface densities and resulting subsurface PROW densities, which mirror surface densities (Bertaud 2018; Webster 1914), contributes to greater utility revenues for individual companies operating in NYC, as compared to revenues received from less dense parts of their service areas. The extent to which utilities' NYC property

tax payments (NYS Real Property Tax Law, Article 18) and business tax payments (NYC Administrative Code, Title 11) are based on subsurface, infrastructure valuations or low rates applied to revenues generated within NYC and do not reflect the NYC subsurface PROW value and negative direct burial externality costs collectively constitute a gap in utility payments to NYC (utility pricing gap). This historical utility pricing gap, embedded in the NYC sociotechnical regime, is a root cause of NYC's subsurface spaghetti problem and NYC's difficulty in leveraging innovative subsurface infrastructure to solve subsurface and surface PROW problems. Adjusting private utility payments to close the utility pricing gap would provide a revenue source to finance utilidor construction and long-term operation and maintenance costs, which would change the 'calculus' of actors within the regime (as discussed below). Thus, the meta-transition will require simultaneous municipal planning reform to include the subsurface PROW and utility pricing gap closure.

3.2 RCA: NYC

NYC's subsurface utility history exemplifies the RCA problem where each individual NYC-based utility's rational, economic decisions yield collectively irrational economic outcomes and increasingly iterative negative impacts due to the lack of effective coordination (Hockett 2015, 3, 5–6). The private utilities seek to maximise profit within imposed New York State Public Service Commission (NYSPSC) service standards and rates. The public water and sewer utility seeks to maximise infrastructure investment, while maintaining affordable rates in the context of debt service rate covenants. Continuing the sociotechnical regime's direct burial method, despite the availability of modern design and technology, costs the private and public utilities more over the long term, with diminishing returns and suboptimal system performance and resiliency due to the apparent inability to avoid predictable infrastructure degradation and accidents. Objectively, these cannot be rationally preferred outcomes. Yet the regime institutionalises stakeholders' interrelationships, practices and policies that directly cause this collectively irrational result. Thus, unless abated, the regime's internal trajectory will allow these increasingly negative economic results to continue and prevent the meta-transition from beginning (Hodson et al. 2012; Egyedi and Sprico 2011).

Government is the only actor with authority to act on behalf of the stakeholder group to transform the regime by changing the 'calculus' of each individual actor so that current economically 'rational' decisions leading to irrational outcomes 'cease to be individually rational' (Hockett 2015, 24; Webster 1914; Smith, Stirling, and Berkhout 2005; Coenen, Benneworth, and Truffer 2012). In the context of the meta-transition, only government can change the equation by:

- officially planning for the subsurface PROW as it does for its buildable surface development
- compelling utilities to produce subsurface infrastructure location data for public safety and official mapping and planning purposes
- treating consumption of the inelastic subsurface PROW area as a market issue as it does consumption of its buildable surface area to accurately price utility payments to include the subsurface PROW value (Bertaud 2018, 82; Webster 1914, 201)

- revising NYSPSC tariffs for NYC utilities to reflect the utility pricing gap (which includes both subsurface PROW value and negative direct burial externality costs) at levels sufficient to finance utilidor construction, operation, and maintenance and change the regime's 'calculus' (Kahn 1988).

3.3 CTA: NYC

NYC must have the legal and operational capacity to effect the meta-transition (Hammer 2009, 8–14; Smith, Stirling, and Berkhout 2005; Chourabi et al. 2012). CTA analysis of NYC (as the RCA change agent) assesses 'local capacity in relation to other tiers of government and private sector and non-governmental organization stakeholders' (Hammer 2009, 3) and outlines NYC's legal capacity to act within and upon its sociotechnical regime, thereby revealing its existing powers to affect the meta-transition and identifying any limits to those powers. CTA analysis of NYC, as a municipal corporation, is summarised below and reveals that NYC has most of the necessary authority to effect the meta-transition but will likely require some New York State (NYS) level support to close the utility pricing gap to finance utilidors.

NYC effectively owns, on behalf of the public, the PROW from the road surface and sidewalks through the soil and rock beneath and can fully regulate the PROW, as a NYS delegated power, including regulating private utility use for transmission infrastructure (Sapir; NYS General City Law, Article 2A, §§ 7, 10; NYS Vehicle & Traffic Law, §§ 134, 148; NYS Highway Law, § 2(4), 102, 139; NYC Charter, § 383; McQuillan, §§ 30.06, 30.11, 30.32, 30.38, 30–39, 30.40). NYC's DOT extensively regulates the utilities' ability to cut and excavate streets for transmission infrastructure repair, replacement, and expansion (NYC Rules, Title 34, Chapter 2), but fails to leverage its powers (NYC Charter, § 2903 (5)) for active planning, inspection, and enforcement to prevent damage, reduce negative direct burial externality costs, and extend the design life of streets as is now done by other municipalities (Kalayil and Peterson 2020).

The NYC Department of City Planning (DCP) focuses almost exclusively on NYC's buildable surface, and rarely requires submission of limited subsurface plans in NYC's uniform land use review process (ULURP). DCP's authorizing law, however, does not restrict its planning powers to the surface (NYC Charter, Chapter 8). DCP could regulate the subsurface PROW through its street mapping power (NYS General City Law Article 3, §§ 26, 29; NYC Charter, § 191 (b)(3)) and through the NYC Planning Commission's authority to 'plan for the city's development and … the physical planning and public improvement aspects of all matters related to the development of the city.' (NYC Charter, §§ 191 (a), (b)(8) and (b)(1), 197-c, 197-c (6), 197-c (12), 197-d, 198, 199, 363; Schwarz and Lane, pp. 877–878). While the reciprocal surface and subsurface resource relationship is the foundation for subsurface PROW mapping and planning, NYC long ago abandoned use of a master plan as the legal comprehensive planning standard for zoning activities and uses flexible requirements for comprehensive planning on a sub-city scale – typically to operationalise changing public policy objectives (NYS Charter Revision Commission for NYC, pp. 11, 20–21 and 116; NYC 1989 Charter Revision Commission Report, p. 29; Barnett, pp. 40–67).

Historically inadequate, subsurface infrastructure location data from all NYC serving utilities will impede DCP's initial efforts to map and plan for the subsurface. Imperfect subsurface utility infrastructure data consists of each utility's historical, paper-based and

updated electronic data, which are not integrated with other utilities' imperfect data, due to fractured governmental control exacerbated by historical antagonistic relationships, post-9/11 security fears, and insufficient funding for data activities (Rozsahegyi and Macfarlane 2017, 3–4; Webster 1914, 201). In the absence of locational data, urban economics principles would permit an initial assumption that subsurface PROW utility infrastructure density distribution mirrors surface density and provide an order of magnitude to initiate subsurface planning change (Bertaud 2018). Meta-transition would derive further support if NYC roadway practitioners treated the subsurface spaghetti problem holistically as a continuum of opportunities to drive the meta-transition, instead of as exogenous and uncontrollable impediments (Hooimeijer and Maring 2018, 20). DCP would be a key actor collaborating with public and private utility engineers, as infrastructure experts. Unfortunately, NYC has no precedent for this type of collaboration (von der Tann et al. 2020, 144, 150; Hooimeijer and Maring 2018, 2; Curiel-Esparza, Canto-Perello and Calvo 2004).

NYC has two legally available utilidor financing options and one option based on prior precedent that would require state legislation. Each has different trade-offs (Garvin et al. 2000, 41–42). The first pair of options consist of (1) NYC general obligation debt (NYCGO) either alone or in combination with NYC Transitional Finance Authority (NYCTFA) debt and NYC Municipal Water Finance Authority (NYCMFWA) debt and (2) the '63-20' financing vehicle permitted under Internal Revenue Code Revenue Procedure 82–26 (formerly Revenue Ruling 63-20). The third option is based on various NYS-created, revenue-based authorities for NYC, such as NYCMFWA and NYCTFA. This would involve creation of aa new revenue-based authority for utilidors and other 'smart' city infrastructure. Financing utilidors solely through NYCGO debt would have the RCA change agent control finance as part of NYC regime change, but NYCGO debt would be subject to NYS constitutional debt and operating limits, as well as competing capital needs for limited debt capacity. NYCTFA and NYCMFWA debt would be limited by their debt-service coverage ratio covenants and competing capital needs. Using the 63-20 debt option would permit NYC to test utilidors on a project basis and approximate the benefits of true public-private-partnership financing, which NYS law does not authorise. The 63-20 corporation's debt would not be NYC debt, and its board of directors could include all NYC regime stakeholders and provide them with a manageable opportunity and reason to resolve their relationship issues on specific projects. A new NYS authority created on behalf of NYC to finance, construct, and/or operate 'smart city' infrastructure (including ICT systems) would (1) authorise debt service, operating, and maintenance payments by each utility and appropriately leverage utility revenues for utility-created problems; (2) leverage closing the utility payment gap in tandem with NYSPSC rate tariff changes to channel subsurface PROW value and negative direct burial externality costs toward an infrastructural solution; and (3) establish parameters for an operating and management agreement. The incremental tariff rates would be included in utilities' base rates and are the mechanism to change the regime's calculus so that direct burial is no longer the economically rational choice (Hockett 2015; Kahn 1988).

Despite long-term cost savings, the higher initial construction costs of utilidors compared to direct burial operates as a barrier to NYC utilidor implementation (Canto-Perello and Curiel-Esparza 2013; Curiel-Esparza and Canto-Perello 2012; Luo et al. 2020). However, BIM-enabled design and prefabricated off-site construction would reduce

installation costs (Canto-Perello and Curiel-Esparza 2013; Garcia and Berrade 2009) and technical 'state-of-the-art' research could lead to further cost reductions (Rogers and Hunt 2006). Additional challenges for utilidor implementation, beyond increased initial costs and balancing unequal utility risks and benefits of the participating utilities for which the full analysis proves economic sense (Alaghbandrad and Hammad 2020), would be addressed as part of any financing arrangement and include complex public-private asset governance issues for planning, implementation, finance and operations over the utilidor's life. These issues would be reflected in utilidor design, covering geotechnical and engineering issues, and a governance framework that includes utilidor infrastructure safety, including threat-type security considerations, and worker safety; planning and design based on demographic estimates to accommodate future expansion without utilidor reconstruction; and, resolving legal and financial issues, including utilidor ownership and occupancy rights, obligations, liability and insurance considerations, payments and utilidor operations management (Canto-Perello and Curiel-Esparza 2013, 2–6). The resulting ownership and/or occupancy, finance and management framework for construction, operation and maintenance of a public-private asset would be the basis for a binding agreement to permit financing that would also include dispute resolution procedures among participants and some level of administrative flexibility (Canto-Perello and Curiel-Esparza 2013, 4–5). Such an agreement covering the utilidor as a public-private asset under the PROW must relate to NYC as the governmental entity in charge of the PROW and as the public utility owner with infrastructure in the utilidor. Governance practices followed in other places with utilidors and financing agreements from other NYC large-scale, complex construction projects could provide templates to adapt for utilidors within existing construction, legal and finance practices.

4. Discussion

The foregoing analysis demonstrates that NYC, alone or with NYS legislative and regulatory assistance, has the capacity for 'deliberative intervention to stimulate broad, systemic (including behavioural) changes' (Hodson et al. 2012, 791) to initiate the necessary meta-transition for utilidor implementation. NYC's roadway reconstruction projects; major private utility expansion projects; instances of major disruptions caused by subsurface infrastructure failures; and repeated excavations in roadway segments critical for mobility all represent opportunities for the initial strategic stages of the meta-transition to be followed by long-term systematic utilidor implementation. Economic analyses of landscape pressures described below would further quantify benefits to the local economy from the meta-transition and supplement LCCBA, because potential long-term benefits over costs, on their own (as noted below), will be insufficient to change the NYC regime's embedded practices. (Smith, Stirling, and Berkhout 2005; Coenen, Benneworth, and Truffer 2012).

4.1 Possible landscape pressures

The 2014 East Harlem gas explosion that killed eight people and injured 70 did not operate as a landscape pressure on the NYC sociotechnical regime to initiate regime change, providing profound evidence of the regime's obduracy (Kiger 2014; McGeehan 2015). The National Transportation Safety Board found the 2014 explosion was caused

by ConEd's faulty gas pipe connection and DEP's failure to repair a sewer main, on which the gas pipe rested, that DEP knew had been leaking for at least eight years, thereby eroding the soil and creating a void (McGeehan 2015). NYC's multiple other predictable major utility transmission main breaks (Dunlap 2015), most of which have root causes in inaccessible infrastructure causing undesirable SOGR levels and asset conditions, also have not yet operated in the aggregate as an effective landscape pressure. Other potential landscape pressures discussed below could, however, evolve and accelerate the meta-transition.

Nassau County's recently authorised Water Supply Regionalisation feasibility study to evaluate using NYC's water supply to provide Nassau County with an additional source of drinking water to resolve water stress issues from continuing Long Island aquifer pollution could evolve into an effective landscape pressure. (NYS FY 2021 Executive Budget, p. 71) If this study results in NYS tapping the water system it created for the *developing* NYC metropolitan area to service Nassau County (which is within the *current* NYC metropolitan area), it could galvanise NYC, which has tolerated water loss from undetected leaks, to move more quickly to the meta-transition (Schwartz and Larocco; Plagianos).

Another landscape pressure could develop when taxation, in the form of 'congestion' pricing, fails to solve Manhattan's surface PROW congestion since road congestion will always be an urban problem because surface PROW area supply is finite and inelastic (Bertaud 2018, 172; Webster 1914, 201). Realising that taxation alone cannot solve congestion would make subsurface infrastructure solutions that are amenable to user fees, such as underground parking garages (Broere 2013, 1530) and subsurface traffic bypass tunnels (Broere 2013, 1531), attractive options to further manage and reduce surface PROW congestion, pollution and noise, thereby further supporting utilidor implementation. Despite high capital costs of transferring surface uses underground, if a fee-based project LCCBA shows benefits exceeding costs, the project will be economically justified and a candidate for fee-based financing (Bertaud 2018, 176–177; see Fitzsimmons 2018 and BQX 2018), and NYC may become receptive to these types of infrastructural solutions to unresolved surface PROW congestion.

Finally, 'smart' city pressures, coupled with the reality that a city cannot be 'smart' when its utility infrastructure is buried in the dirt, may operate to support NYC regime change. Direct burial constrains the ability of public and private utilities to leverage advanced ICT to monitor and manage their systems remotely to optimise system performance and realise 'smart' city direct cost savings. Furthermore, quickly evolving technology for electric vehicles will permit vehicles to 'connect' with surface PROW infrastructure and communicate with them to realise a number of 'smart' city transportation policies that 'dumb' streets will not permit. Direct burial in NYC's 'complete' streets that include a variety of sustainable street applications, such as porous asphalt, pervious concrete and a variety of landscape features to capture stormwater, will increase street excavation and restoration costs (NYCDOT 2020). Construction material technology may eventually permit the roadway to charge electric vehicles (Hannon 2021). To the extent that NYC streets include more sustainable and 'smart' city features, street excavation and restoration costs will only increase and limit the ability of NYC to achieve its policy objectives, thereby potentially operating as a landscape pressure.

4.2 Incremental change

In the immediate absence of effective landscape pressures, NYC can undertake incremental activities listed below:

1. NYC can use innovative subsurface designs and technology short of utilidors, such as trenchless technology techniques, removable pre-cast pavements and moving feasible private utility assignments under the sidewalks (Olympic Associates Company 2006).
2. NYC can revise its roadway excavation rules to implement most aspects of Chicago's life cycle damage prevention program (Kalayil and Peterson 2020) for proactive role in planning, inspection and enforcement to increase roadway design lives, reduce subsurface infrastructure damage from accidental excavation strikes, and produce current subsurface infrastructure locational data on a prospective basis.
3. Strategic opportunities posed by NYC's roadway reconstruction projects, major private utility expansion projects, instances of major disruptions caused by subsurface infrastructure failures, and repeated excavations in roadway segments critical for mobility can support development of a pilot utilidor program (Olympic Associates Company 2006; Edison 2006), using 63-20 project-based financing; excavations resulting from NYC Council Reso. 1445-A/2020 may also support this option.
4. NYC can revise ULURP to include consideration of subsurface PROW network impacts for more land use action types and develop a subsurface infrastructure layer to the city street map with subsurface infrastructure location data.
5. Future studies of undergrounding power lines in NYC (NYC Council Intro. No. 2189/2021) should use local construction and trenching cost data instead of abstracting from area-wide data, including ConEd's current undergrounding projects (Moro 2021) and consider utilidors to mitigate some of the costs identified previously (OLTPS 2013).
6. NYC can develop a public education campaign to increase public awareness of the subsurface PROW infrastructure network and its connection to the larger systems for greater stewardship and understanding of avoidable direct burial costs (Webster 1914, 200).

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