Influence of Task Complexity in Shaping Environmental Review and Engineering Design Durations

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Abstract: Timely completion of environmental reviews for transportation projects has been highlighted as a sore point for performance management by public agencies and industry alike. However, despite its importance, few academic studies investigate project-level performance during the environmental review and engineering design or examine which factors influence it significantly. In this study, we observed 560 transportation projects that the Georgia Department of Transportation completed from 2011 to 2015. We modeled distinct processes for three National Environmental Policy Act document types—programmatic categorical exclusion, categorical exclusion, and environmental assessment—and investigated detailed durations for environmental review activities associated with regulatory agency relation management, consultant relation management, and internal project management. Adopting task complexity theories, we then examined the influence of four dimensions of task complexity on project performance, measured by the overall durations of the environmental review and engineering design. By investigating performance empirically, this study contributes to methodological advancement and theory development in studies on environmental review. This research contributes to the body of knowledge through the creation of task complexity models to empirically examine the effects of different dimensions of task complexity on environmental review and engineering design durations. **DOI: 10.1061/(ASCE)ME.1943-5479.0000649.** *©2018 American Society of Civil Engineers.*

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Introduction

One area of consensus across successive White House administrations has been the need to improve the efficiency of environmental review for transportation infrastructure projects. In the twenty-first century, Presidents Bush, Obama, and Trump have all issued executive orders aimed at streamlining the federal environmental-permitting process associated with transportation projects (Executive Orders 13274, 13604, 13766, and 13807). This has been matched by important provisions aimed at streamlining environmental review in several transportation bills passed into law in 1998, 2005, 2012, and 2015 (TEA-21; P.L. 105-178, SAFETEA-LU; P.L. 109-59, MAP 21; P.L.112-141, and FAST; P.L. 114-94). It has been further reinforced at the agency level through the Federal Highway Administration's (FHWA) Every Day Counts (EDC) initiative, which aims to improve environmental sustainability and shorten the project delivery process (FHWA 2018). A key argument running throughout these considerable efforts is that current environmental regulatory processes are too complex, generate delay, and hinder the efficacious development of transportation infrastructure.

Although the existing research literature demonstrates that the environmental review process is complex, it is difficult to distinguish these factors from the overall complexity of transportation infrastructure projects (Luther 2012). There is some evidence of the potential cascading effect that complexity in the environmental review can have on the duration and delay in the engineering design process (Hansen et al. 2007; Lamb 2014; Trnka and Ellis 2014). Yet there remain many challenges to understanding the relationships between complexity in the environmental review process, project complexity, and project duration, prompting recent case studies and investigations in transportation, construction, and planning (Lv and El-Gohary 2016; Roberts and Whorton 2015; Stich and Holland 2011).

In recent years, engineering management research has laid a foundation of theories, concepts, and tools through studies of complexity at the task and project levels of behavior that can help in understanding the relationship between environmental review and project duration in infrastructure projects. In developing our conceptual model, we noted a growing convergence in the conceptualization of the task complexity and project complexity models to explore the interfaces of components of larger endeavors such as an infrastructure project. Environmental review can be conceptualized

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as a key component in the interface management of projects, which Ahn et al. (2017) described as contact points linking relatively autonomous organizations, or subunits, which are interdependent and cooperate to achieve a larger system objective. In this study, we explored the interface between environmental staff and consultants, contributing key information to the engineering design teams of a state department of transportation.

Project complexity studies have developed a variety of strategies for identifying project components as critical sources of complexity. In addition to Ahn et al.'s (2017) focus on interface management, Lou et al. (2017b) examined project components that contribute to types and levels of complexity in construction projects. Gransberg et al. (2013) developed a framework for distinguishing between routine and complex infrastructure projects by mapping project complexity across five dimensions of infrastructure projects: technical, schedule, cost, financing, and context. In each of these approaches, components can also be understood to be subsets of tasks with interfaces coordinated in the larger project.

Task complexity studies have also been drawn to the interface between actors, subunits, and project components. Haerem et al. (2015) explored the network of paths and events linking actors that ultimately lead to a task outcome. Such networks are inclusive of paths that span the interfaces of autonomous units and can be clustered into distinctive project components. Engineering management studies included task complexity as a component of project complexity to investigate impacts on project success (Girmscheid and Brockmann 2008; Liu and Li 2012; Lu et al. 2015; Luo et al. 2017a). In these studies, task complexity was closely connected to project success, but highly dependent on inconstant relationships between tasks (Luo et al. 2017b). Weick and Roberts' (1993) case study of task complexity in landing operations on aircraft carriers provided an early example of studies encountering tasks requiring the coordination and cooperation across interfaces of distinct project components and professions.

Although task complexity and project complexity studies have converged on the goal of developing classification strategies for project components within larger complex systems, there has been little dialogue across the levels of analysis. In the transportation sector, the motivation for understanding project complexity stems in large part from the growing use of large-scale public–private partnerships for the development of infrastructure projects. This has led researchers to emphasize the distinctiveness of complex projects from routine project management (Gransberg et al. 2013). In contrast, task complexity research has tended to focus at a microlevel of teams engaged with complex technical procedures (Braarud 2001) and the motivations of actors engaged in complex tasks (Park et al. 2008). These distinctive levels of analysis reflect a longstanding and useful division of labor among management scholars influenced by organization theory and organization behavior. However, in order to better understand the relationship between environmental review and project performance, we need a richer understanding of how task complexity shapes performance at both the component level and the overall project level.

Because we were studying two critical components of infrastructure projects (environmental review and engineering design), we drew upon conceptual models of task complexity. Our strategy for observing task complexity was also influenced by approaches taken in project complexity studies of classifying the level of complexity of project components. We took this approach because we observed performance data of 560 infrastructure design projects completed by the Georgia Department of Transportation (GDOT) over a five-year window (2011–2015). In this study, we compared and contrasted different sources of task complexity on the duration of the environmental review process as well as on the duration of the overall engineering design using hazard models. To further help untangle the relationship between project complexity and environmental review complexity, we developed and explored hazard models for each class of environmental review.

We examined data drawn from the project performance monitoring system measuring the time durations devoted to the tasks associated with key project components. We focused on engineering design projects from the main program delivery portfolio of GDOT. In the classification schemes used by the FHWA, these would be considered routine projects rather than complex projects (Shane et al. 2011). Although this eliminated the large public–private partnerships delivered through GDOT's Innovative Program Delivery Office from our sample, it captured the portfolio of projects that occupied the majority of work performed by GDOT staff and their contractors (GDOT environmental staff estimated that routine projects accounted for 90% of the effort devoted to environmental review and program delivery). Fig. 1 presents a stylized timeline of events in the preconstruction process for routine GDOT projects. Gransberg et al. (2013) noted that routine projects under the FHWA classification scheme exhibited high levels of variability in complexity in terms of technical specifications and the coordination of schedules and work among the project teams. Routine projects are a major target of public policies aimed at streamlining the relationship between environmental review and project duration.

In the next section, we present the key conceptual relationships linking task complexity and performance in the context of the environmental review or infrastructure projects. We then review our research methodology using hazard models to examine the influence of various dimensions of the task complexity on the duration of the environmental review and the overall engineering design project. After a discussion of our key findings, we explore the implications for engineering management practices and public policy.

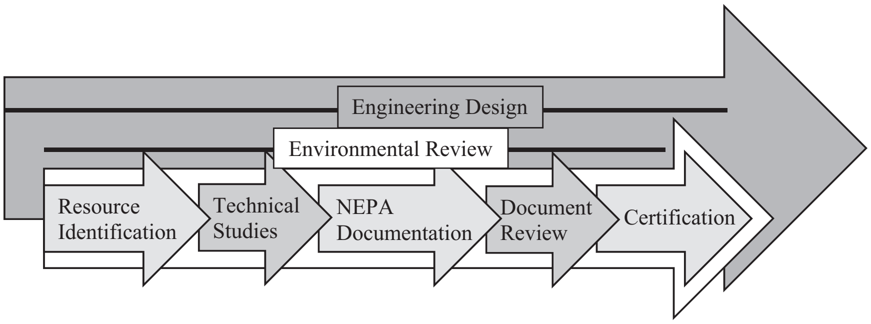

Fig. 1. Project timeline.

Environmental Review, Task Complexity, and Project Performance

At the crux of all this political attention toward streamlining are the provisions set forth in the National Environmental Policy Act (NEPA) of 1969. NEPA is an umbrella procedure for environmental compliance. Before FHWA can approve federal funding, the project sponsor [such as a state department of transportation (DOT)] must demonstrate compliance with all applicable federal, tribal, and state requirements. Consequently, NEPA documentation coordinates regulation from FHWA, the Environmental Protection Agency, the US Army Corps of Engineers, the Fish and Wildlife Service, the US Parks Service, the National Marine Fisheries Service, state and tribal historical and cultural oversight organizations, and other relevant agencies. As a practical matter, this means that NEPA documents summarize information from technical reports addressing the environmental issues for each project. Importantly, NEPA also specifies the different levels of technical studies and documents required for compliance. State transportation agencies work with the FHWA to determine the level of environmental review for each project. Each level of environmental review specifies the components of task complexity in terms of the number of individual tasks, work products, and information-sharing requirements. Table 1 provides a rank ordering and description of the level of task complexity associated with each of the following levels of environmental review: environmental impact statement (EIS), environmental assessment (EA), categorical exclusion (CE), and programmatic categorical exclusions (PCE). The projects observed in this study were concentrated in the EA, CE, and PCE categories, because no EIS projects completed environmental review during the time period we observed.

Task complexity studies build upon the early works of Wood (1986) and Campbell (1988), which conceptualized tasks as objective phenomena stimulating individuals to use physical and knowledge inputs to generate outputs. Task complexity was then observed through additive indices of inputs, paths of work, paths of information, and outputs or products associated with the production process. Haerem et al. (2015) extended this conceptualization to apply to networks of paths leading to outcomes that can be applied beyond the individual level to larger aggregations of actors such as project teams and project component teams. Wood (1986) developed three conceptual dimensions of task complexity that we used in this study to explore component, coordinative, and dynamic complexities.

Component complexity captures the number of steps and information paths associated with a task. The environmental review process has been strongly criticized by practitioners and policy makers as adding an excessive number of tasks that can delay engineering projects (Oppermann 2015). However, the relationship between environmental review and engineering design tasks is nuanced, because existing studies considered project conditions themselves as critical factors in the environmental review process (Hansen and Wolff 2011; Kabir and Momtaz 2014; Lamb 2014).

State DOTs classify transportation projects by project improvement types, which vary in terms of the number of skill sets used, the number of technical studies performed, the level of technical sophistication required, the number of engineering design procedures required, and the number of approvals necessary (both internal and external to the agency). We used this classification system

Table 1. NEPA document types (requirements and relative complexity)

Type	Number	Required for projects[a]	Requirements	Steps	Tasks	Actors
EIS	0	Projects whose actions will have a significant effect on the environment	– Resource identification – Technical studies – Draft NEPA documentation – Final NEPA documentation – Supplemental NEPA documentation – Federal review – ROD documentation – ROW certification – LET certification	22	220	10
EA	55	Projects in which the significance of the environmental impact is not clearly defined	– Resource identification – Technical studies – Draft NEPA documentation – Final NEPA documentation – Federal review – FONSI documentation – ROW certification – LET certification	14	102	10
CE	247	Projects that do not individually or cumulatively have a significant environmental effect	– Resource identification – Technical studies – NEPA documentation – Federal review – ROW certification – LET certification	8	31	8
PCE	258	Projects that are very small in scale and have minor to no environmental impacts	– Resource identification – Technical studies – NEPA documentation – ROW certification – LET certification	7	26	7

Note: FONSI = finding of no significant impact; ROD = record of documentation; and ROW = right-of-way.

[a]Quoted from GDOT 2017.

to observe the level of component complexity, because it provides a rank ordering of project improvement types based on an estimation of the number of associated procedures, steps, and information paths. Although the level of aggregation was different (project versus individual), the logic of the relationship was not so different from the original conceptualization of component complexity developed by Wood (1986). We tested the following hypothesis in this investigation.

Hypothesis 1 (H1): Increases in component complexity lead to increases in the durations of the environmental review and engineering design.

Coordinative complexity refers to the relationship between tasks as they serve as inputs into overall project output. In Wood's (1986) original conceptualization, coordinative complexity consists of the number and sequence of acts that precede and contribute to the production of a task by an individual. For transportation projects, a similar logic can be used, because the engineering design process requires coordination across a wide variety of actors and project components. Among the factors identified by the existing studies on environmental review, consultant relation management is closely related to coordinative complexity (Erickson 1994; Hansen et al. 2007; Lamb 2014; Yang and Wei 2010). When a project outsources to environmental or engineering consultants, the number of precedential and sequential acts associated with environmental review increases during the cycle of document submission, review, return, and revisions between principal and agent. Therefore, projects in which task products are outsourced are likely to have higher coordinative complexity.

A similar logic pertains to projects that involve funding from local governments, in which case they would directly hire engineering design and environmental consultants. State transportation agencies are responsible for reviewing all local projects that interact with state and federal infrastructure or those in which the funding involves a mix of local public expenditures with state and federal resources. In practice, local projects require more coordination with a broad range of stakeholders, so a local project can have more acts associated with task products than a state project under the same project improvement type and NEPA document type. Combining the findings of the environmental review studies and coordinative complexity, we tested the following hypothesis.

Hypothesis 2 (H2): Increases in coordinative complexity lead to increases in the durations of the environmental review and engineering design.

Dynamic complexity is determined by changes that affect the relationships between task inputs and products, creating shifts in the knowledge or skills required for a task. Wood (1986) indicated that the sum of differences across specified time periods for any or all of the indices for the two dimensions of static complexity—component and coordinative complexities—is an index for dynamic complexity. In environmental review, dynamic complexity can be shaped by higher-level entities such as federal regulatory agencies that provide oversight (i.e., information cues) to lower-level entities such as state transportation agencies. State agencies and consultants closely monitor changes in regulations and regulatory guidance, because these changes have direct and material impact on task products such as technical studies, NEPA documents, and engineering designs. Regulatory changes are usually incorporated in the form of revisions to environmental documents and represent a key source of dynamic complexity at the project level. Many studies attribute problems with environmental review to changes in regulations and regulatory guidance. The most common challenges of the environmental review are found in communication and coordination practices with federal agencies on regulations and regulatory guidance (Erickson 1994; Kreske 1996; Lawrence 2013; Morrison-Saunders and Bailey 2009). Thus, in relation to dynamic complexity, we tested the following hypothesis.

Hypothesis 3 (H3): Increases in dynamic complexity lead to increases in the durations of the environmental review and engineering design.

The previous three hypotheses build directly out of Wood's (1986) model of task complexity. This study adds a fourth factor, subjective complexity, which was developed through industrial engineering studies of team performance as a concept for observing the interactions between task characteristics and task performer characteristics. At the organizational level, employee conditions such as experience and professionalism are critical for handling complex tasks (Perrow et al. 1986). Task complexity is a subjective evaluation that changes over time (Park et al. 2008) and can be subject to task performers' prior knowledge as a source for interpreting information cues. Among the factors identified by previous studies, internal management factors such as training, turnovers, and staff seniority can be connected to complexity subject to interactions with task performers.

Among the many internal factors that affect the environmental review process, limited staff and insufficient training were consistently identified by many studies (Hansen et al. 2007; Kabir and Momtaz 2014; Lamb 2014; Trnka and Ellis 2014). These studies suggested that agencies need to employ a sufficient number of qualified staff, and that staff need to use up-to-date environmental review processes, training modules on environmental review, sufficient NEPA decision support systems, and processes for responding to inquiries from internal agency staff. By adopting an additional dimension, subjective complexity, which affects coordinative and dynamic complexities, we tested the following hypothesis.

Hypothesis 4 (H4): Increases in subjective complexity lead to increases in the durations of the environmental review and engineering design.

Table 2 presents a condensed reference to the four dimensions of complexity we modeled in our study, providing brief descriptions for each as well as examples of how they might manifest in an infrastructure project.

Research Methods

Data Collection: Variables Based on Task Complexity

Luther (2012) provided a summary of the issues encountered in studies of streamlining transportation projects: data limitations,

Table 2. Task complexity dimensions

Dimension	Description
Component complexity	The additive number of acts and information cues involved in completing a project (i.e., the number of tasks required, the level of technical sophistication)
Coordinative complexity	The relationship between actors and subtasks which serve as inputs into the project process (i.e., management of consultant relationships)
Dynamic complexity	Changes that affect component complexity or coordinative complexity during the life of a project (i.e., regulatory changes that change the number of tasks required to complete a project)
Subjective complexity	Complexity as subject to a task performer's prior knowledge as a source for interpreting information cues (i.e., training, technical expertise, seniority)

nonenvironmental reasons for project suspension, wide task variations associated with project improvement types, various approaches to implementation, and nonlinear causal relationship between environmental issues and project delay. In this study, we attempted to address many of these challenges by focusing directly on the time durations (measured in calendar days) of the environmental review and engineering design for transportation projects. The study sample consisted of 560 engineering design projects. We selected this sample from the population of projects that completed GDOT's environmental review between 2011 and 2015 by excluding (1) maintenance projects, (2) projects that were intentionally delayed and (3) projects with duplicate or incorrect data entries. We used all the data that were available at the time of collection, spanning from 2011, when GDOT started collecting the high-quality performance data, to 2015, when we accessed them. Data from this period offer a representative look at how transportation agencies operate, because they demonstrate normal operations at an agency that had successfully adjusted to the high level of outsourcing now commonplace among public organizations (Gen and Kingsley 2007).

This study observed durations by developing two envelope measures of the time in days from the beginning to the completion of an engineering design and the environmental review conducted as part of the project (see Table 3 for a description of dependent variables). Environmental review duration and engineering design duration are stopwatch measures marking initiation and completion of activities. This approach was consistent with the way in which federal authorities monitored performance on EIS projects measured in months between initiation (e.g., agency issued a notice of intent) and completion (e.g., agency issued a final record of decision). The contrast between these stopwatch measures gave the ability to compare time devoted to environmental activities within the larger envelope of time devoted to overall engineering design.

Component complexity was observed in the hazard models through nominal measures of different project types. State DOTs classify engineering design projects according to the primary project improvement type, which vary considerably in the level of task complexity. This study observed the variability in task complexity by developing a rank order of the number of procedures, actors, technical studies, and information paths by project improvement type (Table 4).

This ranking was constructed by the researchers through an archival review of the manuals and template checklists created by GDOT, which provide the following guidance: (1) steps in the design procedures, (2) distribution of responsibilities across project team members, (3) types of technical information required for the design, (4) the schedule for when information and reports are to be completed, and (5) offices to coordinate with, both internal and external to the agency. This ranking was confirmed through interview data from GDOT staff.

Coordinative complexity was observed through four measures that capture the variety of ways in which engineering design projects are performed. First, this study captured coordinative complexity through the variable state funding, which describes whether a project is at the initiative of the state government or local governments. Second, it explored the complexity that is created through the outsourcing of government services. In-house design captures whether the engineering design was produced by a consulting firm or GDOT design staff. In-house NEPA documentation captures whether the NEPA document was produced by GDOT NEPA analysts or a consulting firm. Similarly, consultant ecology review captures whether the ecological technical report (which was produced

Table 3. Description of variables

Classification	Variable	Description	Number	Mean (SD)
Dependent	Environmental review duration	Time required to complete environmental review for a project (days)	560	769.3 (1,034.17)
	Engineering design duration	Time required to complete total engineering design for a project (days)	452	1,209.8 (1213.70)
Component complexity	Improvement type	A nominal measure indicating 11 improvement types of engineering design work		See Table 4
Coordinative complexity	State funding	Whether local funding is involved government (local funding = 0) or not involved (state funding = 1)	560	1 = 363 0 = 197
	In-house design	Engineering design work performed by a consultant (=0) versus by a state design office (=1)	428	1 = 153 0 = 275
	In-house NEPA documentation	NEPA documentation performed by a consultant (=0) versus by a GDOT NEPA analyst (=1)	452	1 = 143 0 = 309
	Consultant ecology review	Ecology documents reviewed by a consultant (=1) versus by a GDOT ecologist (=0)	490	1 = 89 0 = 401
Dynamic complexity	Total regulatory changes	Out of 10 selected regulatory changes initiated during the time period of this sample, the total number of regulatory changes that required an adaptation by GDOT and/or consultants during an environmental project	522	0.75 (1.02)
	Bat regulatory change	A nominal measure indicating that the change in bat regulations occurred during an environmental project	522	1 = 143 0 = 379
	Bat change lead time	The number of days from the announcement date of the bat regulatory change that extended areas that require Indiana and Gray Bats surveys to the starting date of the environmental review process	560	198.2 (324.23)
	Procedural change lead time	The number of days from the announcement date of the state procedural change for the Preliminary Field Plan Reviews step to the starting date of the environmental review process	560	70.1 (175.75)
Subjective complexity	Project manager workload	The number of projects in the sample that the GDOT project manager leads	559	15.6 (14.54)
	NEPA analyst workload	The number of projects in the sample that the GDOT NEPA analyst leads	544	35.7 (21.99)
	Ecologist workload	The number of projects in the sample that the GDOT ecologist leads	490	32.7 (21.25)

Table 4. Component complexity ranking by project improvement and NEPA document type

Complexity rank	Project type	PCE		CE		EA		Total	
		Rev	Des	Rev	Des	Rev	Des	Number	%
1	Bridge replacement (added capacity)	0	0	2	2	6	3	8	1.43
2	New bridge construction	0	0	3	3	4	3	7	1.25
3	New road construction	0	0	0	0	4	3	4	0.71
4	Major widening	0	0	3	2	23	16	26	4.64
5	Bridge replacement (no added capacity)	7	7	72	52	2	1	81	14.46
6	Relocation (added capacity)	0	0	0	0	2	2	2	0.36
7	Relocation (no added capacity)	0	0	1	1	0	0	1	0.18
8	Bridge rehabilitation (added capacity)	0	0	0	0	1	1	1	0.18
9	Bridge rehabilitation (no added capacity)	0	0	3	3	0	0	3	0.54
10	Reconstruction (added capacity)	0	0	2	1	3	2	5	0.89
11	Reconstruction (no added capacity)	0	0	2	2	1	1	3	0.54
12	Minor widening	9	8	12	11	1	1	22	3.93
13	Traffic engineering	40	26	13	8	1	1	54	9.64
14	Environmental improvements	0	0	1	1	0	0	1	0.18
15	Safety improvements	166	148	50	40	4	4	220	39.29
16	Restoration, rehabilitation, resurface	4	3	3	3	0	0	7	1.25
17	Other enhancements	32	26	80	65	3	2	115	20.54
	Totals	258	218	247	194	55	46	560	100

Note: Des = engineering design; and Rev = environmental review.

by a consulting firm and serves as a source for NEPA documentation) was also reviewed by a consultant for an agency approval.

Dynamic complexity was observed through four variables designed to capture major changes in the environmental regulatory process that influenced projects during the 2011–2015 time period. The measure total regulatory changes provides a count of the number of regulatory changes that occurred during a particular project. In interviews with GDOT staff, we learned of two major initiatives requiring extensive communication with regulatory and contracting partners. Two measures were designed to capture a major change in federal regulations with regard to monitoring endangered bat species extending their habitat into Georgia that was considered by state environmental staff as a significant change. Bat regulatory change is a nominal measure of whether the bat regulatory change occurred during the environmental review. Bat change lead time measures the number of days between the change in bat regulations and the initiation of the environmental review for a project. Procedural change lead time captures another measure of dynamic complexity by observing the number of days each project experienced between the announcement of a major procedural change at GDOT and the initiation of the environmental review.

Subjective complexity was observed through three measures of workload for GDOT officials. Project manager (PM) workload, NEPA analyst workload, and ecologist workload are counts of the number of projects that each type of GDOT staff member was responsible for in the data set at the time that they were engaged with these projects.

Research Design Based on NEPA Document Types

The research design of this study incorporated the different types of NEPA documentation into the modeling strategy. One of the challenges in understanding the relationship between environmental review and engineering design is sorting between the sources of task complexity. There is high variability in the complexity associated with different project improvement types (Table 4). The study sample indicated distinct clusters of projects associated by classes of environmental review processes and different project improvement types. More than 80% of EA projects were associated with the most complex project improvement types. More than 95% of PCE projects were associated with the least complex project improvement types. CE projects were more broadly distributed but ranged between the other clusters in projects with middle levels of complexity.

Data Analysis: Event History Analysis

Event history analysis is commonly used to study survival rates of populations and failure rates of physical systems or any other phenomena in which the dependent variable of interest is the time until an event or change of state occurs (Blossfeld et al. 1989). Therefore, the relevant functions are referred to as risk of the event, hazard rates, and survival times. In this case, there was a single event of interest, namely, the completion of the environmental review or the engineering design, which was a desired outcome so it seemed awkward to refer to it as a risk or a hazard. However, to maintain uniformity with the literature, this study used the established terminology.

We developed two hazard models for projects complying with each class of NEPA document: one exploring the dimensions of task complexity on the environmental review duration and one for the total engineering design duration. We tested a Kaplan-Meier model of the survival process stratified by NEPA type to determine whether to use separate models and then tested a Cox regression with different types of hazard functions to select the best fit. Given the long time periods associated with engineering design projects and the associated environmental review process, this study used piecewise proportional hazards (PPH) with increments of 100 days, or based its models on Weibull distributions when appropriate (for a further description of the modeling process, see the "Results" section). The type of hazard model developed for each category is indicated in Table 5. These models assessed the influence of covariates (i.e., task complexity variables) on the likelihood of the duration coming to an end in each successive time period.

The main objective of the data analysis was the estimation of the survival function and the hazard rate of the completion of the environmental review and engineering design durations. The first indicates the probability of the completion event occurring after time t. The second indicates the instantaneous risk of completion occurring in the vanishingly small interval following time t given that it has not been completed by time t (Blossfeld et al. 1989; Mills 2011). The mathematical expression for the survival function is

$$S(t) = \Pr(T \geq t)$$

where T = positive random variable that indicates the duration of the process. The mathematical expression for the hazard rate is

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leq T < t + \Delta t | T \geq t)}{\Delta t}$$

Results

Estimation of Survival Functions

In this study, we first tested for differences in the dynamic process of the three types of projects with a Kaplan-Meier model of the survival process stratified by type of project. This was necessary in order to determine whether the models of the hazard rate function should be estimated separately or the project data could be pooled to gauge the effect of the covariates.

Table 5. Hazard models used

Project type	Environmental review	Engineering design
PCE	Piecewise proportional hazards (PPH) model using an exponential form. (PPH increments = 100 days)	Proportional hazards (PH) model based on a Weibull distribution.
CE	PPH model using an exponential form. (PPH increments = 100 days)	PPH model using an exponential form. (PPH increments = 100 days)
EA	Accelerated failure time (AFT) model based on a Weibull distribution.	PH model based on a Weibull distribution.

A visual inspection of the survival function curves in Figs. 2 and 3 suggests that the three processes were different from each other, both for the environmental review and engineering design. A log-rank Mantel-Haenszel test confirmed that the survival curves for each environmental review type were different. The survival curves also revealed that not only were the average durations different for the three types of projects, but that the dynamic processes were different, especially for the EA projects with respect to the other two. The probability that these projects remained pending after time t, given noncompletion at that time, stayed high and decreased slowly for EA projects, yielding an almost concave curve. This means that most projects had an inherently longer duration that extended beyond a minimum threshold, after which they were completed in rapid succession. Both CE and PCE projects have convex survival curves that decrease rapidly at first with tails that decrease slowly after that. This means that many projects had a high probability of completion during the early stages, but after a certain point, their durations tended to extend significantly. This occurred for about 20% of cases.

Estimation of Hazard Rates with Effects of Covariates

There were several options in the selection of regression models for the hazard function in these cases. Because this study did not have strong theoretical guidance relating the nature of the environmental review and design processes to the hazard function, several models were estimated and their statistical properties were compared via likelihood ratios (higher likelihood is better), the standard errors of the coefficients (smaller is better), and graphical properties of the estimated hazard functions to select the best model (Blossfeld et al. 1989, p. 176; Mills 2011, pp. 144–145). The process was as follows:

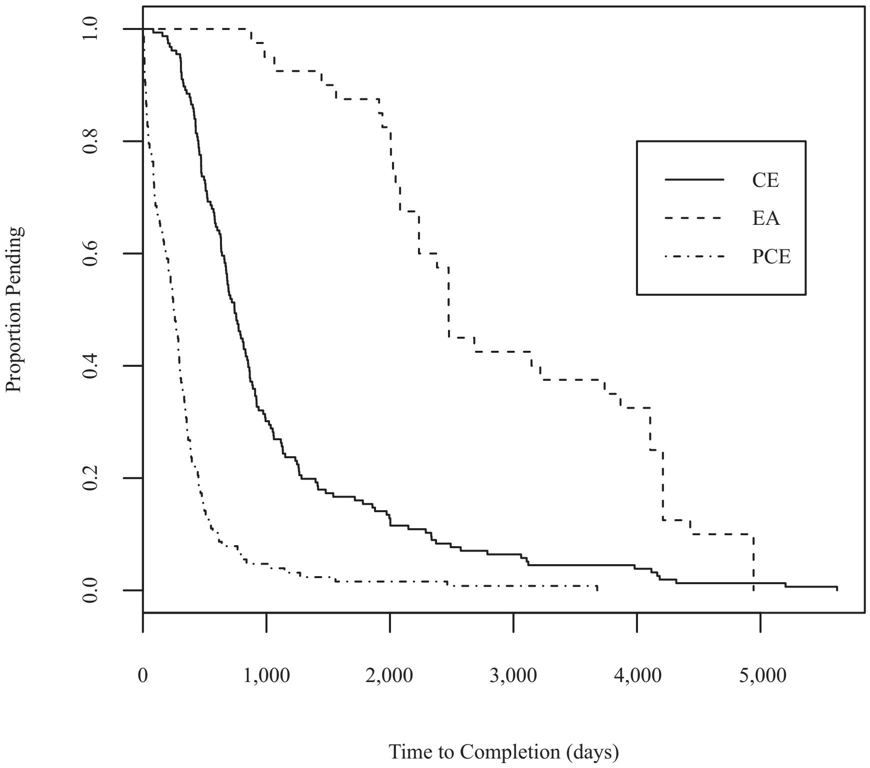

Fig. 2. Survival curves for the environmental review duration.

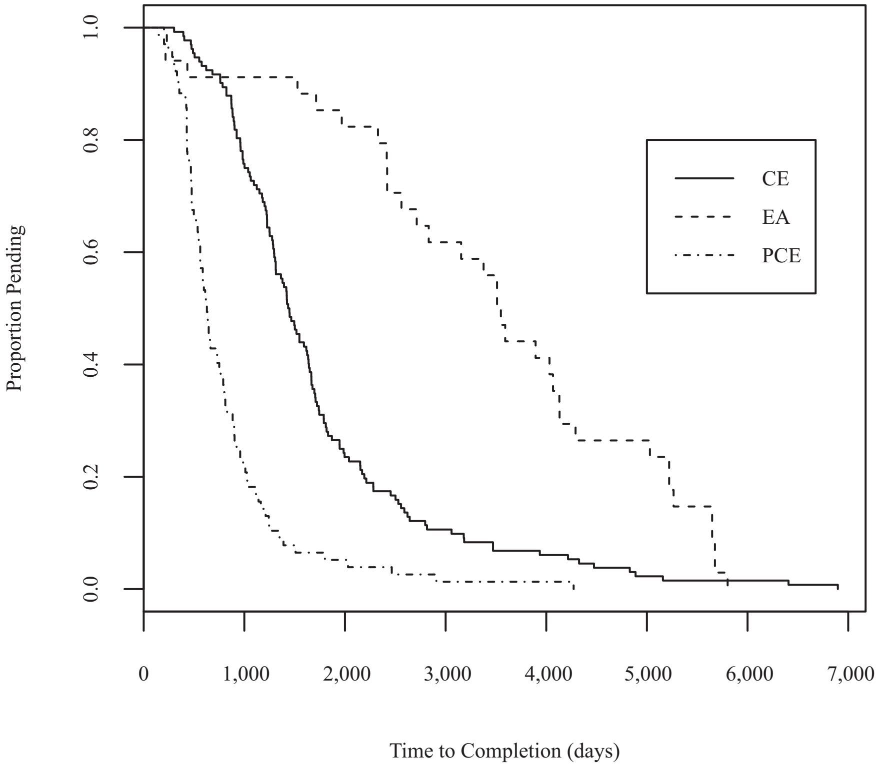

Fig. 3. Survival curves for the engineering design duration.

For each case, this study tested a Cox regression, which assumes proportional hazards by construction; parametric models based on the Weibull distribution in two forms—proportional hazards (PH) and accelerated failure time (AFT); and, finally, an exponential model with piecewise constant hazards to explore the possibility that specific periods have fixed hazard rates but are different from each other due to stages internal to the process (Mills 2011, pp. 144–145). All the models resulted in similar results, but this study analyzed the one with the best fit according to these criteria. The selection of the Weibull distribution was based on the flexibility of its parametrization, which allows for decreasing, constant, or increasing hazard in a simple way from the actual estimation. Other distributions had shapes that were unlikely for the project data being used in this study, as exploratory runs confirmed.

Tables 6–8 provide the results of the models for each type of documentation process describing the influence of component, coordinative, dynamic, and subjective complexities on task performance as measured by the time durations of environmental review and engineering design.

Influences of Task Complexity on EA-Type Projects

The best model for the environmental review duration of EA projects was a parametric model based on Weibull distribution with AFT. For the engineering design duration, the best model was a parametric model also based on the Weibull distribution but with PH.

The overall models were significant (bottom of Table 4), even with the relatively small number of events (40 completed environmental reviews and 34 engineering designs). The complexity of the EA-type project was reflected in the number of factors affecting the duration of both the environmental review and engineering design durations and the different models capturing the dynamics of each. Component complexity was a significant factor explaining time durations for EA projects in the environmental review and total design duration. Table 4 indicates that most EA projects were associated with more complex forms of engineering design. All improvement types that were significant contributed to increases in the time to completion, either by expanding the time scale (time factors greater than 1 in the AFT model) for environmental review or decreasing the hazard (negative percentages in the PH model). The other complexity factors affected the environmental review and engineering design durations differently. Elements of coordinative complexity (i.e., funding by the state government and ecology review conducted by consultants) and dynamic complexity (i.e., changes in regulation) all increased the hazard of the engineering design (shorter completion times). In all these cases, the effects were very large, increasing the hazard from five to hundreds or thousands of times. These large effects were due to the influence of a relatively small number of cases that were carried out under state government funding and reviewed by consultants and had drastically shorter completion times. Whereas many cases had durations of thousands of days, these were completed in just a few weeks. The cases with regulatory changes did not overlap with the state-sponsored and consultant-reviewed cases. They were another small group that showed a shorter duration on average compared with the rest.

None of the factors relating to coordinative and dynamic complexity influenced the environmental review of the EA projects. In contrast, measures of subjective complexity associated with project staff workloads had similar effects on both environmental review and engineering design durations. The NEPA analysts' number of projects multiplied the time scale of environmental reviews by 1.01 and decreased the hazard by 10% for the engineering design duration for each additional project. The ecologists' number of projects, conversely, tended to accelerate the process, shrinking the time scale of environmental reviews, because it was only 0.99 of the original scale for each additional

Table 6. Hazard models for EA projects

Variable	Environmental review (AFT model: Delay factor)	Total engineering design (PH model: Hazard change)
Bridge replacement add cap.	Exp(0.5515) = 1.74***	100*(0.018–1) = −98.2%**
Bridge replacement no add cap.	2.1**	−100%***
Major widening	1.53**	−98.6%***
New bridge	1.44**	−98.5%***
New road	—	−99.2%***
Reconstruct add cap.	2.98***	−98.6%***
Reconstruct no add cap.	0.4***	—
Relocation add cap.	1.77***	−95.6%**
State funding	—	31,508.5%***
Consultant ecology review	—	222,154.1%***
Total regulatory changes	—	598.2% (per change)**
Bat regulatory change (yes/no)	—	8,500.8%**
NEPA workload	1.01 (per project)**	−10% (per project)***
Ecologist workload	0.99 (per project)***	9.7% (per project)***
Model statistics	Scale = 0.22	Events = 34
	Weibull distribution	Total time at risk = 118,176
	Loglik(model)= −321.3	Max. log. likelihood = −274.48
	Loglik(intercept only)= −339.3	LR test statistic = 52.94
	Chisq = 35.95 on 23 degrees of freedom,	Degrees of freedom = 16
	$p = 0.042$**	Overall p-value = 7.71531×10^{-6}***
	Number of Newton-Raphson iterations: 6	
	$n = 40$	

Note: LR = likelihood ratio test statistic. Statistical significance indication: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table 7. Hazard models for CE projects

Variable	Environmental review (PH model: Hazard change)	Total design duration (PH model: Hazard change)
Restoration, rehabilitation, resurface	762%***	435.9%**
Consultant ecology review	144%***	—
Total regulatory changes	—	104.7%***
Bat regulatory change (yes/no)	—	−74.9%***
Bat change lead time	0.5% (per day)***	—
PM workload	4% (per project)**	—
NEPA workload	−1% (per project)**	1.6% (per project)***
Model statistics	Events = 156	Events = 132
	Total time at risk = 165,498	Total time at risk = 228,451
	Max. log. likelihood = −1,129.1	Max. log. likelihood = −1,021.5
	LR test statistic = 103.87	LR test statistic = 38.08
	Degrees of freedom = 21	Degrees of freedom = 18
	Overall p-value = 5.9297×10^{-13}***	Overall p-value = 3.7827×10^{-3}***

Note: LR = likelihood ratio test statistic. Statistical significance indication: **$p < 0.05$; ***$p < 0.01$.

project, and increasing the hazard of completion of the engineering design by 9.7% for each additional project. These reductions in time may reflect the greater experience of the ecologists, with more projects in their dockets.

Influences of Task Complexity on CE-Type Projects

The best models for environmental review duration and engineering design duration for CE-type projects were both parametric based on PPH, which assumes the exponential distribution, with time segments of 100 days, which were like waiting periods for delivering comments and returning documents in iterative processing between GDOT and consultants. Because both models were proportional hazard models, the coefficients had the same interpretation in which an increase in the hazard was interpreted as increasing the probability of project completion.

Four types of effects were present in the CE models for both the environmental review and engineering design durations. First, component complexity associated with one type of improvement—restoration, rehabilitation, and resurfacing—was much different from the rest because it had faster completion by almost eight times, in the case of environmental review, and more than five times in the engineering design duration. These projects were few in number and had much lower component complexity than most others (Table 4). Although CE projects spanned a wide number of project improvement types, component complexity was not a significant factor (but for one improvement type) explaining the duration of either the environmental review or the overall project. Second, consultant ecology review increased the probability of completion of environmental review by 144%, meaning that it was a mitigating factor in the effect of coordination complexity. Third, regulatory changes that reflected dynamic complexity had a mixed effect on the hazard of completion.

Table 8. Hazard models for PCE projects

Variable	Environmental review (PH model: Hazard change)	Total design duration (PH model: Hazard change)
Bridge replacement no add cap.	−83.8%***	—
Minor widening	151%**	—
Safety improvements	65.4%**	125.2%**
In-house NEPA	104.5%***	—
Bat change lead time	0.2% (per day)**	—
PM workload	4.6% (per project)***	—
Model statistics	Events = 127	Events = 77
	Total time at risk = 41,262	Total time at risk = 62,266
	Max. log. likelihood = −787.71	Max. log. likelihood = −556.99
	LR test statistic = 102.28	LR test statistic = 48.43
	Degrees of freedom = 15	Degrees of freedom = 15
	Overall p-value = 4.77396×10^{-15}***	Overall p-value = 2.17093×10^{-5}***

Note: LR = likelihood ratio test statistic. Statistical significance indication: $^{**}p < 0.05$; $^{***}p < 0.01$.

The presence of bat regulation changes delayed completion of the engineering design by reducing the hazard by 74.9%. Increased lead time increased the hazard of environmental review by 0.5% for each additional day in advance the regulation change was introduced. The two models showed similar effects due to bat regulatory changes but captured them differently. In the former case, regulatory changes added dynamic complexity and, therefore, delayed completion. In the latter, more lead time compensated for it and helped in accelerating the environmental review. On the other hand, the total number of regulatory changes reduced duration by 104.7% for each additional change. This effect may be due to learning. As the same project dealt with more changes, it could apply the lessons and systematize the process rather than be thrown off course by the exceptional change.

Finally, workload contributing to subjective complexity also played a role, with mixed effects. Program managers with more projects increased the hazard of environmental reviews by 4% for each additional project, but the number of NEPA analysts' projects reduced the hazard by 1% for each additional project. On the engineering design duration side, only the number of NEPA analysts' projects had an effect, but in the opposite direction from the environmental review, increasing the hazard by 1.6% per additional project.

Influences of Task Complexity on PCE-Type Projects

From the survival curves, it can be seen that PCE-type projects had a faster dynamic, with a probability of completion higher than EA and CE projects. The best models for environmental review and engineering design durations were both based on proportional hazards, but the former was parametric based on PPH with time segments of 100 days, and the second was parametric based on the Weibull distribution. Except for one in the environmental review, all the significant effects in both models tended to increase the probability of completion. The only exception was the bridge replacement with no added capacity that reduced the hazard of the environmental review by 83.8%, leading to slower completion. Other component complexity improvement types influencing the environmental review were minor widenings and safety improvements, both increasing the hazard by 151% and 65.4%, respectively. Safety improvements also increased hazard for the engineering design duration by 125.2%. This was the only factor influencing engineering design duration, which was consistent with the reduced complexity of PCE projects with respect to the others. The environmental review duration, on the other hand, also was influenced by having NEPA documentation performed in house (coordinative complexity), bat change lead time (dynamic complexity), and PM number of projects (subjective complexity). In all three of these factors, the effect was to increase the hazard by 104.5%, 0.2% for each additional lead day, and 4.6% for each additional project, respectively.

Hypothesis Outcomes and Discussion

The results of the hazard models facilitate an understanding of the relationship between task complexity and the durations of environmental review and the overall engineering design. The findings of these models provide a basis for observing key complexity dimensions in the development of environmental activities within an engineering design project. This study demonstrated that the three different classes of NEPA documentation most commonly dealt with in the environmental review were resolved through unique processes, both for the environmental review and engineering design. Table 9 summarizes the results.

More complex component conditions were connected to longer durations of the environmental review and engineering design, providing support for Hypothesis 1. This was particularly pronounced in EA projects and PCE projects. However, it was less pronounced in CE projects, save for one project improvement type. This suggests that agencies do have the opportunity to set expectations more realistically and in accordance with the component complexity of the task. Implementing performance monitoring systems to track project component complexity can help inform internal process management and streamline project lifespans.

The conditions of outsourcing and funding as coordinative complexity revealed some unexpected results across two of the hazard models. As expected, the decreased coordinative complexity associated with state funding and in-house NEPA review increased project performance (in terms of shorter duration times), but the results defied expectations about ecologist outsourcing. Although it increased the coordinative complexity of the project, outsourcing the ecological review to consultants could increase performance for the engineering design in EAs and both the engineering design and environmental review for CEs. These results conditionally provide support for Hypothesis 2. When dealing with coordinative complexity, practitioners should take contextual factors into account, and consider the nuanced relationships that exist between actors on their teams.

The results showed that it took time for consultants and environmental staff to respond to regulatory changes or new procedures and the influence of dynamic complexity on project performance was subject to timing of interactions with task performers. This implies a close relationship between dynamic and subjective complexities, which conditionally provides support for Hypothesis 3. In

Table 9. Hypotheses and results across complexity dimensions

		EA		CE		PCE		
Complexity dimensions	Variable	Rev	Des	Rev	Des	Rev	Des	Hyp
Component	Bridge replacement (added capacity)	+	+			+		+
	Bridge replacement (no added capacity)	+	+					+
	New bridge	+	+					+
	New road		+					+
	Major widening	+	+					+
	Relocation (added capacity)	+	+					+
	Reconstruction (added capacity)	+	+					+
	Reconstruction (no added capacity)	−						+
	Minor widening					−		+
	Safety improvement					−	−	−
	Restoration, rehabilitation, resurface			−	−			−
Coordinative	State funding		−					−
	In-house NEPA Documentation					−		−
	consultant Ecologist review		−	−				+
Dynamic	Total regulatory changes		−		−			+
	Bat regulation intervention		−		+			+
	Bat change lead time			−		−		−
Subjective	PM workload			−		−		+
	NEPA workload	+	+	+	−			+
	Ecologist workload	−	−					+

Note: + = makes project durations longer; − = makes project durations shorter; Des = engineering design; Hyp = hypothesis; and Rev = environmental review.

practice, there should be an institutionalized system in place for practitioners to track and update information on regulatory and policy changes so that they can maximize the time available for adaptation.

This study added subjective complexity to a structuralist's task complexity model, and the results demonstrated that it played a critical role in project performance, providing mixed support for Hypothesis 4. Although the existing literature suggests that understaffed conditions can cause delays in the process, the hazard models revealed some contradictory results for the influence of staff workload across the NEPA document types. These counterintuitive results invite additional research. One interpretation is that increased staff experience may be relatively more important than workload under certain conditions, such as complex EA projects. Although agency context is important for interpreting subjective complexity, the results presented here could identify several recommendations concerning project staffing, such as assigning experienced ecologists for EA projects and minimizing the overall workload of NEPA analysts.

This study not only empirically examined the influence of the task complexity factors on project performance, but also advanced task complexity theories by (1) developing a model of four different dimensions of task complexity as explanatory factors for the durations of environmental review and engineering design processes and (2) applying this model at the project level of analysis. Moreover, varied performance between NEPA document types suggests unique dynamic processes for both environmental review and engineering design.

Conclusions

The environmental review process has been highlighted by public agencies and industry alike as a sore point for performance management in transportation projects. Environmental review is critical to successful and timely project delivery because other project phases, such as roadway and bridge design, right-of-way (ROW) acquisition, utility relocation, and construction, are dependent on NEPA documentation and acquisition of environmental permits (Hannon et al. 2014). A project manager's ability to establish and maintain an overall project schedule is highly sensitive to accurate estimates of the time environmental review will require.

The importance of understanding and developing ways to mediate the drivers of project delay has been demonstrated by the high level of attention that NEPA issues have been given at both the federal and state levels. In light of the significant policy efforts devoted to streamlining the environmental review process for transportation projects, this information should be helpful for designing future initiatives and streamlining innovations. The EDC program used by FHWA to streamline environmental review seeks to identify and deploy proven, yet underutilized, innovations that address challenges to the review process. This study contributes to the EDC program's main goals of increasing efficiency, shortening delivery time, and saving resources. Quantifying the impact of subjective complexity can provide project managers with an enhanced model for estimating the duration of the environmental review process. This is necessary to ensure that projects receive the appropriate amount of time scheduled for their review. This study can help project managers allocate resources more efficiently for environmental review tasks.

Our results help illuminate how task complexity impacts infrastructure project performance. As many existing studies point out, the interdependency of the tasks, the context of the environmental review within the overall engineering design, and the environmental review process should not be analyzed in isolation. This study developed a model for assessing the influence of different types of task complexity on project durations, allowing the environmental review process and total design processes to be disaggregated and studied separately. The results demonstrated that analysis of project-level task complexity can offer a useful way of understanding relationships between complexity and performance. However, from a theoretical perspective, our study also points to a need for more theory building. One of the limitations of our study is that we developed our models building by necessity on both task complexity studies and project complexity studies. We find that these lines of scholarship often share similar conceptual roots. We also note that the division of labor between the two, while fruitful, may break down as both lines of scholarship continue to explore the networks of activities and other interrelationships between subelements of projects.

Our findings also elucidated key differences between NEPA categories in the environmental review process. The duration of the engineering design subject to an EA review process was influenced by all four components of task complexity. However, the duration of the associated environmental review was influenced by only component and subjective complexity. In contrast, for projects subject to CE and PCE review, all four dimensions of task complexity influenced the duration of the environmental review, while the overall engineering design duration was influenced by only component complexity in PCE projects and three dimensions of complexity in CE projects. This study showed that projects with different NEPA categories followed distinct timelines and had distinct task characteristics that reacted differently to changes in project conditions. At GDOT, incorporation of this evidence has led agents to reprioritize projects under review and move away from a one-size-fits-all approach to the review process. Our findings on subjective complexity also were supportive of agency strategies for template development, outsourcing, and standardization of reporting requirements for environmental review documents as part of the streamlining process. Understanding these differences can improve project managers' understanding of choke points in the NEPA process that demand hands-on attention and can lead agencies to better management of the environmental review process. Future research should be sure to disaggregate these categories to ensure clear and unbiased results when further examining differences in influences of the four dimensions of task complexity as well as relationships between the dimensions.

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Notation

The following symbols are used in this paper:

$h(t)$ = hazard rate function;
$S(t)$ = survival function;
T = duration of process; and
t = time.

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