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Research article

Let sleeping bats lie: Analyzing institutional adaptation to environmental regulatory change through Adaptive Management theory

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ABSTRACT

Employing a case of a state transportation agency, we examine how complex institutions which integrate outsourcing within a bureaucratic process adapt to environmental regulatory changes. In 2012, two endangered species of bats were located outside of their established ranges in northern Georgia. These discoveries required the Georgia Department of Transportation (GDOT) to comply with a new set of federal regulations relating to those species when developing its projects. This article examines how GDOT adapted to new and unforeseen regulations in the face of environmental uncertainty. Using archival and interview data, we describe how GDOT engaged in Adaptive Management (AM) to internalize environmental changes (i.e. sufficiently stabilize the situation so that the project can get back on track). We also examine the role of outsourcing in bureaucratic agencies as an avenue for AM and suggest extending the AM model to describe mediating actors in the adaptive process. Furthermore, we investigate the impact adaptation had on project outcomes by analyzing 81 bridge projects, which are most susceptible to these environmental shocks, from a sample of 429 transportation projects using multivariate regression. We show that GDOT engaged in initial decision-making, iterative learning, and collaboration through a multi-tiered communication structure. We then present evidence supporting the narrative that these strategies helped it mitigate the impact of subsequent environmental shocks and improve project outcomes over time through adaptation.

1. Introduction

State transportation agencies frequently encounter unexpected changes in the environmental and regulatory conditions surrounding their projects' environmental assessments (Amekudzi and Meyer, 2005; Landres et al., 1999). How they adapt to these shocks can be a key factor in determining how environmental concerns are addressed in infrastructure projects (such as roads, bridges, and ports) as well as how long those projects take to complete. Adaptive Management (AM) is a strategy that uses collaboration and experimentation to generate learning. AM provides a theoretical foundation for understanding agency behavior and performance under conditions of high uncertainty such as those created by environmental shocks (Norton, 2003, 2005). However, current formulations of AM do not fully address increasingly popular New Public Management (NPM) practices which emphasize greater reliance upon market forces and business strategies drawn from the private sector (Barzelay, 2001). We present a case study of the Georgia Department of Transportation (GDOT) as it responded to a series of environmental shocks stemming from discoveries of endangered bats within its jurisdiction. When endangered species were detected in the local environment, normal operations at GDOT were disrupted and mediation was required in order to determine how they should be dealt with on ongoing projects. We focus on how GDOT uses other mediating actors, primarily environmental consultants, to assist in the development of compliance procedures.

AM is often presented as an alternative, and better, approach of environmental management than the structured procedures associated with traditional command and control bureaucracy (Norton, 2015; Holling and Meffe, 1996; Gunderson, 2001a). By observing the use of two common NPM practices, outsourcing (contracting out environmental analyses to private consultants) and performance measurement (monitoring the time taken to get projects approved), we explore the robustness of AM theory in explaining bureaucratic behavioral outcomes.

AM prescribes that policy-makers and their agents should test ambiguities and conflicts which arise due to environmental uncertainty through an iterative decision-making process coupled with rigorous monitoring of environmental performance (Williams, 2011a). AM often

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includes processes for greater democratic engagement with stakeholders as a means of better articulating the competing values associated with an environmental shock (Norton, 2005). It is commonly integrated in collaborative governance, a system of organization focused on incorporating agents and stakeholders from diverse perspectives in the decision-making process (Ansell and Gash, 2008; Innes and Booher, 2004; McGuire, 2006). NPM and more recent movements in administration, such as New Public Service (NPS) (Denhardt and Denhardt, 2007) are also based on prescriptive theories about how management should be conducted. NPM argues for the incorporation of private sector, incentives-based management into the public sector (Hood, 1991). NPS builds off of this, emphasizing attention to elements of collaborative governance such as democratic values (Bryson et al., 2014). Though they prioritize different goals, these strategies can be commensurable with one another. NPM's emphasis on outsourcing can facilitate elements of collaboration promoted by NPS and collaborative governance. Furthermore, its recommendations for rigorous performance review and feedback from stakeholders (or clients in NPM language) are similar to the monitoring and feedback systems in AM.

Similar to many other public agencies in the US, state departments of transportation (SDOTs) rely heavily on performance review (Poister, 1997), and have increasingly expanded their use of consultants (Warne, 2003). Environmental analysts at these agencies organize environmental processes and facilitate project management at the state and federal levels with these external consultants. The consultants themselves might be viewed as having several different roles. First, they might be viewed as agents of the department, providing labor to complete the information needs of bureaucracy. In this context, consultants may be responsible for performing the technical studies and National Environmental Policy Act (NEPA) documentation necessary for environmental approval. Second, they might be considered scientific and technical specialists who apply their expertise to provide a detailed understanding of local conditions, which agency analysts may be too removed to observe. Third, consultants might mediate collaboration between various stakeholders in the decision-making process. These consultants function as mediating actors by brokering collaboration between bureaucratic agents at GDOT, local governments, regulators, research communities, and local stakeholders. We study these three roles that environmental consultants play over a series of transportation projects, examining the relationship between iterative learning processes and the development of bureaucratic compliance procedures. Current formulations of AM do not model collaboration and adaptation as commensurable with bureaucratic organization or account for the role outsourcing plays in the adaptive process. However, when we account for NPM and collaborative practices in our case study, we observe a more complicated relationship between adaptive and bureaucratic processes. After the regulatory landscape changed, GDOT maintained the hierarchical structure typical of a bureaucratic organization. However, it engaged in structural adaptation with the consulting community, shifting its relationships to provide consultants with input into how to respond to the new regulations. Furthermore, members of the consulting community adapted to the market, deciding whether to specialize in bats themselves and act as mediating agents for GDOT in dealing with the issue, or defer to other firms, subcontracting bat-related work out to their peers. This altered individual firms' relationships with GDOT and each other. The complexity of these relationships, and the mediating role consultants had the flexibility to maintain, allowed adaptation to occur within the overall bureaucratic architecture at GDOT.

Section 2 reviews the existing literature concerning AM, then describes the specific context for AM at GDOT. Section 3 describes the case context, our data, and research methodology. Section 4 investigates our results, first describing AM engagement by GDOT and detailing the ways in which it deviates from the AM model, and then quantitatively evaluating the impact that this management strategy had on project outcomes. Section 5 suggests improvements to the AM model, and discusses the policy implications of our research. Section 6 reviews our conclusions.

2. Adaptive Management Models

Traditional command and control approaches to management have been criticized as ineffective for environmental subjects (Holling and Meffe, 1996). Top-down methods often result in unexpected drawbacks for both human and natural resources due to inflexibility of the bureaucratic structure. For SDOTs, the importance of maintaining project schedules and budgets can drive management behavior. However, management strategies that focus on understanding the complex environment in which their operations are embedded are better suited for adapting to uncertain conditions because they account for the entire system rather than a single variable which may not be well defined (Gunderson, 2001b; Norton, 2015).

AM was developed as a process for resource supervision which facilitates learning and is particularly useful for problems that can be described as “wicked” (Rittel and Webber, 1973; Walters and Hilborn, 1978). This strategy is an effective method of management for natural resources (Freeman, 2010; Norton, 2005). It provides a method for managing subjects under uncertainty by treating them as natural experiments in order to sort through rival theories of ecosystem variation (Gunderson, 2001b). Situations which exist under uncertainty, have spatial or temporal variation, require cost-benefit analyses, or are constrained to institutional or stakeholder requirements, all justify the use of AM (Gregory et al., 2006). It can be employed in any situation where management could realistically be improved by reducing uncertainty (Williams, 2011b).

When managers determine their initial goals and then iteratively alter their decisions in order to learn how to improve management outcomes within the context of their specific environment, their behavior is consistent with AM. This marks a departure from most public management theories where agencies negotiate organizational goals that then set the parameters for acceptable decision-making and performance at the project level (Rainey, 2014).

Early conceptualizations of AM divide the process into two phases of behavior (Nichols et al., 2007), which we incorporate into our study. Managers first focus on *goal determination* (the process of making decisions about how a subject should be managed) using multi-partner collaboration. This creates an arena for discourse involving potentially conflicting values and methodological ideas. *Goal determination* is characterized by collaboration between public officials, scientific and technical specialists, and other stakeholders. For state transportation projects, the goal determination group consists of representatives from federal and state regulatory agencies, local governments, SDOT staff, and consultants working for the SDOT.

In cases of environmental shock, an AM process may begin at the project level and build over time toward a larger organizational goal setting process as knowledge from different projects accrues in an iterative fashion. The collaborative, and in some cases democratic, aspect of goal setting draws in knowledge across a range of disciplines and ideologies to form management goals and objectives (Norton, 2015). *Iterative management* can then take place as managers evaluate how close each project comes to meeting their objectives and integrating what they learned from that success (or failure) into the next round of goal setting. By not stating firm organizational goals up front, agencies can prioritize between management alternatives by weighing their success against each other (Burgman, 2005).

Fig. 1 provides a depiction of the relationship between *goal determination* and *iterative management*, as adapted from Williams (2011a). AM is marked by the presence of multi-partner collaboration and the formation of measurable objectives, decision-making in the face of uncertainty, monitoring and assessment to reduce that uncertainty, learning, and iterative decision-making over time.

For an agency dealing with an environmental shock, the portfolio of

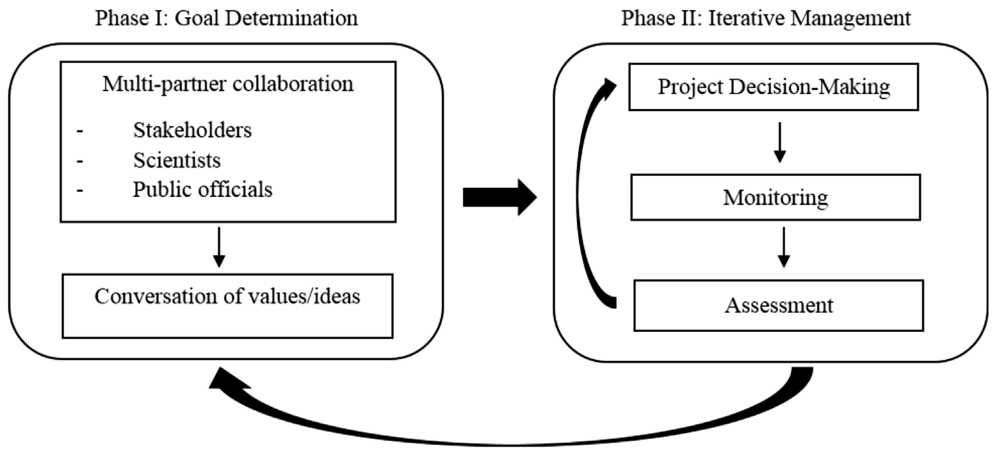

Fig. 1. Adaptive Management Model. Process of goal determination and iterative management.

projects considered during the *goal determination* phase will be defined by the physical and regulatory conditions set by the event (i.e. which jurisdictions contain relevant habitat) and the uncertainty associated with how widespread those conditions might apply. An affected agency may develop sets of projects within this portfolio purposively to experiment with or treat them all the same at the organizational level, opportunistically relying on the adaptation of its consultants to generate learning at the project level.

3. A mixed methods analysis of adaptation to environmental shocks

We use a mixed methods design, developing a case study of managerial adaptations with an embedded statistical analysis. This allows us to examine 1) the extent to which GDOT's adaptive strategy reflects the iterative processes of AM, and 2) the impact that strategy had on project durations.

We develop the illustrative case study design using the conceptual elements of AM described in Fig. 1 to explore whether consultants contribute to *goal determination* and/or *iterative management* at GDOT. This case study focuses on the environmental review phase of infrastructure projects because this is when agencies are most engaged in identifying and developing plans to mitigate environmental shocks. We examine three different ways consultants might contribute to AM at GDOT. First, we examine changes in procedures at GDOT and consulting firms aimed at improving GDOT's ability to identify endangered bat habitat and mitigate damage. Second, we inspect the interaction and communication consultants shared with a variety of actors involved in deliberating how to react to a shock. Third, we explore whether learning generated by consultants carried over to subsequent shocks.

The case study elements of our design organize data temporally into *adaptive events* associated with the discovery of two endangered bat species which were previously unknown to the region, as well as the exposure of indigenous bats to White Nose Syndrome (WNS) which has proven an existential threat to bat species in other regions of the US (Blehert and Meteyer, 2011; Frick et al., 2010; WNS.org, 2018). An *adaptive event* is the introduction of an environmental shock and the regulatory changes it brings for a set of projects, demanding the development of *goal determination* through *iterative management* in order to adapt. The emergence of each *adaptive event* is observed at two levels of behavior. First, we track *goal determination* at the organization level by investigating how GDOT developed guidance about how to adapt to each bat species. Second, we observe feedback from consultants at the project level, giving us a window onto the *iterative management* of each event. We also explore the relationship between *goal determination* and *iterative management* over time.

The qualitative analysis of our case study draws from a mix of archival and interview data. Archival data are sourced from federal and state guidance documents regarding bats and environmental review. We examine a series of 11 GDOT announcements and emails (called email blasts) about bats. The primary purpose of both the emails and announcements was to disseminate up-to-date information about new regulations and procedures to GDOT ecological officers and the consultants who work with them. However, they served not only as a medium through which GDOT could circulate instructions, but as a conduit for ecologists to take part in the ongoing discussion between GDOT and the environmental regulatory agencies it had to answer to. These data give us a strong, if not complete, representation of the general announcements GDOT made during this time. Many of the relevant project-specific discussions were conducted across different media (e.g. phone conversations and in-person meetings) so we do not have an exhaustive collection of communication data, but our sample offers a representative look into what took place. We also analyze a GDOT spreadsheet predicting the scope of impact the regulatory change would have on future projects at the time of the shock. This document contains information on the number of projects GDOT predicted would be impacted as well as their budget.

Interview data about GDOT practices, consultant relationships, and challenges to environmental projects were gathered between October 2015 and June 2016 from consultants and GDOT staff including office managers, analysts, and ecological specialists. Both semi-structured and unstructured interviews were conducted with GDOT staff, including conversations with the ecological specialist charged with developing new regulatory guidance on bats throughout the adaptive events we cover. We also interviewed nine representatives at six (17%) of GDOT's environmental consulting firms, chosen based on performance-based selection criteria. The semi-structured interview protocol we used was designed to explore how communication and organization between GDOT staff and consultants contribute to performance outcomes, and covered topics related to both changes in goal determination and iterative management.

The statistical analysis embedded within our case study is designed to test the impact GDOT's strategy (as revealed by the qualitative analysis) had on project durations. First, since environmental shocks can be disruptive of production schedules and the *duration* of infrastructure projects, we examine the *adaptive performance* of GDOT in terms of the time it took for the environmental review process to be completed in the portfolio of projects associated with each *adaptive event*. Second, we examine the relationship between similar *adaptive events* which occurred at different points in time. One indication of learning that we explore is whether the disruptions to project schedules were reduced between subsequent *adaptive events* as GDOT applied the lessons learned from one environmental shock to the next. Since GDOT's goal was to eliminate delays caused by the new regulations, we

Table 1
Distribution of Projects. Number of bridge projects in each category.

	Uninterrupted	Indiana Bat	Gray Bat
Completed Before Interruptions	24	0	0
Concurrent	31	11	10
Started After Interruptions	14	0	0

* 9 projects were interrupted by both shocks.

consider any reduction in project durations to indicate effective management.

Performance data relevant to iterative management come from a GDOT database which provides the duration of the environmental review process for each project completed between 2011 and 2015. This database is designed to track the schedule for tasks associated with the engineering design for infrastructure projects as well as the tasks associated with projects' environmental review. It is comprised of calendar dates marking when tasks were initiated and completed. These dates do not represent the actual time spent on task by GDOT officers or their consultants. Instead, they are measures of time in process which include the time devoted to adaptations occurring around regulatory changes.

Our analysis focuses on the population of 81 bridge projects included in the sample of 429 total GDOT projects within the cleaned dataset. We chose to examine bridge projects since bridges often provide habitat for bats to roost making those projects much more susceptible to the influence of bats (Keeley and Tuttle, 1999; Davis and Cockrum, 1963). This subset should present the clearest picture of the impact these *adaptive events* had on GDOT. Additionally, we control for the wide variation in project durations due to different project characteristics by including NEPA classification, project type, funding source, and staff experience in our model. Of the 81 bridge projects in this subset, 11 were interrupted by the first *adaptive event* (Indiana Bats) and 10 were interrupted by the second (Gray Bats). The distribution of cases is depicted in Table 1.

Whether or not a project was interrupted by each *adaptive event* is included as a pair of dummy variables called "Indiana Bat" and "Gray Bat" after the shock they represent and coded 1 for projects which were ongoing at the time of each event. Interrupted projects were subjected to the disruptions associated with that event. We expect projects to have longer durations if they were interrupted by either *adaptive event*, but we anticipate a smaller impact from the second event due to agency adaptation occurring in response to the initial shock. Lead time was coded as the number of days after the initial *adaptive event* that each project started. This variable is meant to capture the agency's ability to adapt. If GDOT was effectively adapting, then the more lead time it had available to learn about bats the more expediently it should have been able to complete its projects. We expect project durations to decrease the more lead time a project has had since it would provide GDOT additional opportunity to engage in adaptation.

NEPA classification and project type can drive project durations through the varying level of complexity each type entails, so we include them as dummy variables with Categorical Exclusions (CE) and Bridge Rehabilitation projects as their respective reference groups.[1] Funding source is included as a dummy variable, coded 0 for local and 1 for state funding since projects which are funded locally are subject to a different set of organizational constraints (and often delays) than those run by GDOT. Staff experience can impact the efficiency with which projects are completed and is represented by a trio of dummy variables (for the project's manager, NEPA analyst, and ecologist) each coded 1 for staff who have more than the mean number of projects at their position. The dependent variable, environmental review duration, is measured in days and represents the period of time from the beginning of a project's environmental studies to the end of the review process when it is approved. This measure of project length is used as an indicator of adaptation; the more successfully GDOT was able to adaptively manage bats on each project, the more efficiently it should be able to complete that project. The dependent and explanatory variables in our model are summarized along with basic descriptive statistics in Table 2.

Using Ordinary Least Squares (OLS) multivariate regression in Stata v14.2, we analyze the impact of each *adaptive event* on project durations. We use this analysis to test the adaptive capability of GDOT by examining whether it was able to recover from these disruptions over time. The models we present are the most parsimonious, simple, and interpretable, and are consistent with a variety of robustness checks and alternative specifications. We tested for multicollinearity using variance inflation factors (VIF).[2] We also used a series of F-tests and stepwise functions to assess different model specifications, comparing different models with Akaike's Information Criterion (AIC) (Akaike, 1974). Furthermore, we tested the robustness of our models using bootstrapping at 100, 500 and 1000 iterations and comparison with structural equation models to account for potential latent variables and correlations between error terms in the data.

4. Results

4.1. Adaptive Management process at GDOT

This section presents the context of our case study, describes the sequence of events surrounding the discovery of endangered bats and the regulatory changes that followed, and lays out evidence for GDOT's use of AM to deal with this environmental shock. Fig. 2 details a timeline of events at GDOT.

Prior to 2012, 14 different species of bats were known to live in Georgia. Transportation agents would have to be aware of these species when preparing their NEPA reviews since one was listed as threatened and several others were of state concern.[3] However, since none of these bats were classified as endangered under the Endangered Species Act of 1973 (ESA) GDOT was not forced to comply with any ESA regulations for bats, and was, therefore, much less concerned about the impact its infrastructure projects had on local populations (ESA, 1973).

That changed in June of 2012 when a fifteenth species, the Indiana Bat (myotis sodalis), was discovered inside GDOT's jurisdiction. This is the first of two *adaptive events* we observe in this case study. Indiana Bats have been protected at the federal level since 1967 when they were first listed under the Endangered Species Preservation Act of 1966 and are currently listed as endangered under the ESA (ESPA, 1966; ESA, 1973). Their detection in Georgia prompted ESA regulations for bats to be extended into areas where no such compliance was previously required. This was coupled with a new threat to local bat species since Indiana Bats are carriers of WNS, a fungal disease which has been rapidly spreading through the US, decimating populations of hibernating bats. Population losses in the Northeast, where the disease was first detected, are estimated at roughly 80% (USGS, 2017). For GDOT, this meant that every project taking place within its northern counties had to start complying with a brand new set of unfamiliar regulations.

ESA regulations are administered jointly by the US Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) which operate as two of the regulators with federal authority in the NEPA process (USFWS, 2017). They institute strict requirements in areas where endangered species are present in order to avoid adverse

[1] National Environmental Policy Act (NEPA) classifications include Categorical Exclusions (CE), Environmental Assessments (EA), and Environmental Impact Statements (EIS) in order of increasing complexity. No EIS projects are present in our dataset.

[2] We ensured that none of our independent variables had a VIF exceeding 2.

[3] Threatened Species: Northern Long-eared Bat. Species of Concern: Northern Yellow Bat, Southeastern Myotis, Eastern Small-footed Myotis, Little Brown Myotis, and Tri-colored Bat.

Table 2
Variables. Summary and descriptive statistics.

Variable	Measure	Descriptive Statistics
Environmental Review Duration	Days until project completion	Mean = 1385 Std. Dev. = 1267
Indiana Bat	0 = Uninterrupted, 1 = Interrupted by Indiana Bats	Interrupted = 13.6%
Gray Bat	0 = Uninterrupted, 1 = Interrupted by Gray Bats	Interrupted = 12.4%
Lead Time	Days between initial adaptive event and project's start date	Mean = 85 Std. Dev. = 216
Project Type	0 = Bridge Rehabilitation 1 = Bridge Replacement	Rehab = 3.7% Replace = 96.3%
NEPA Type	0 = Categorical Exclusion (CE) 1 = Environmental Assessment (EA)	CE = 91.4% EA = 8.6%
State Sponsor	0 = Local funding source, 1 = State funding	State = 81.5%
Experienced PM	1 = Project Manager has more than average number of projects	Experienced = 14.8%
Experienced NEPA Analyst	1 = Project NEPA Analyst has more than average number of projects	Experienced = 39.5%
Experienced Ecologist	1 = Project Ecologist has more than average number of projects	Experienced = 34.6%

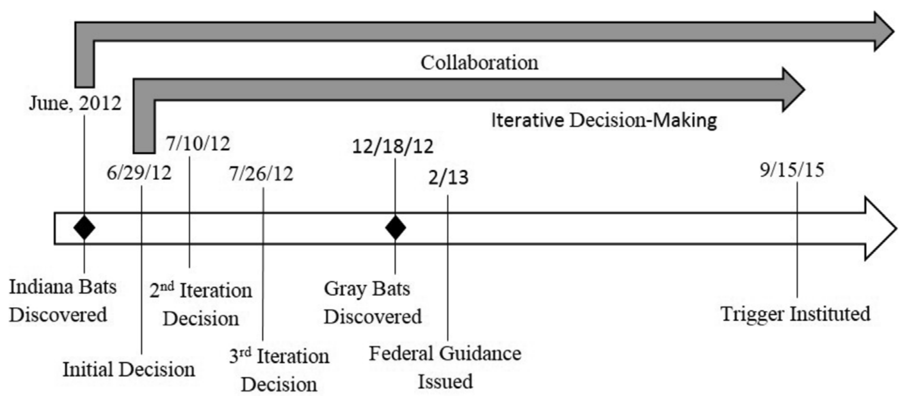

Fig. 2. Timeline. Sequence of events at GDOT.

effects on those populations. These include restrictions on the types of actions which can be taken, and the demand for detailed monitoring, determinations, documentation, and permitting on top of the NEPA process' baseline requirements (EPA, 2005).

This shock was reported as being highly disruptive to GDOT projects in both consultant and GDOT staff interviews. Finding Indiana Bat habitat within GDOT's jurisdiction brought both uncertainty and ambiguity to its environmental review process. Not only was it impossible to determine where individuals of those species would turn up, but it was not immediately clear how they should be dealt with if, and when, they did. Since federal regulations did not specify the best way to survey for Indiana Bats, GDOT had to determine the best method of dealing with them in its regional context out of a long list of possibilities. GDOT staff interviews revealed that the *goal determination* phase involved decision-making about how to specify species ranges and detect bats on-site in Georgia, as well as how to determine the impact projects would have on local bats and translate that into a technical assessment for the review. This phase engaged multiple actors and was an ongoing process culminating in reformations of GDOT goals as learning and feedback were generated through the *iterative management* of individual projects. GDOT responded to this shock by implementing a form of AM within the hierarchical structure of authority demanded by the NEPA process. The tasks involved in the transition from an initial to a final *goal determination* through *iterative management* at GDOT is described in the archival evidence we present and presented visually in Fig. 3.

GDOT engaged in collaboration, initial decision-making in the face of uncertainty, and iterative learning to implement adaptation. It responded to the lack of clarity surrounding the environmental shock by initiating discussion with both federal regulators and its consultants. Archived emails clearly show collaborative decision-making taking place throughout this conversation. GDOT used email to transmit information to its consultants from an ongoing conversation with federal regulators about what types of management changes would be required by the presence of bats. Simultaneously, it used the discussion to gather information from those consultants about conditions in the field. While archival evidence shows that consultants were not formally included in this discussion until June 29th, 2012, when the first set of guidelines were published, we know from consultant interviews that they frequently discuss such guidelines independently with both GDOT and federal regulatory agencies and were thus informally involved in the *goal determination* process.

> *Fri, 29 Jun 2012 21:09:46 "Ecology Update: Indiana Bat (Myotis sodalis)": "We're still working with USFWS, DNR* [Department of Natural Resources]*, and FHWA* [Federal Highway Administration] *to determine how to translate what you find in the field into an effect determination."*

GDOT used this conversation as part of the larger *goal determination* phase of the AM process. It enabled GDOT to think through how the regulations should be applied within Georgia and what the best methods of compliance would be. Although the discussion was a collaborative effort between three different groups of actors, it took place within the structure of a top-down system.[4] After coming to an agreement with federal regulators, GDOT published an initial set of procedural guidelines and range maps for their consultants and ecological staff to use. On June 29th, 2012, after about a month of discussion (according to archival and interview evidence), a set of standards regarding Indiana bats was put in place even though GDOT was unsure about how this approach would work in the field.

[4] Local stakeholders were not included in the goal determination phase, but they could give indirect feedback through their interaction with GDOT agents and consultants during the required public stage (the set of hearings open to the public for locals to engage in discussion about the project) of the NEPA process.

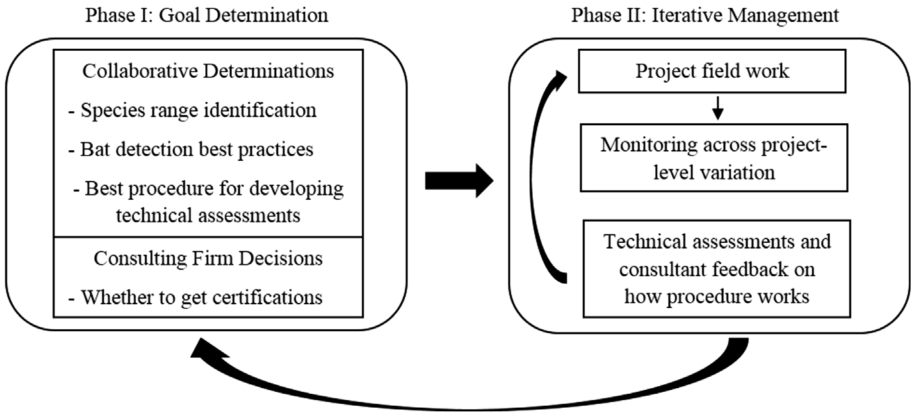

Fig. 3. Adaptive Management at GDOT. Main tasks involved in goal determination and iterative management at GDOT.

Fri, 29 Jun 2012 21:09:46 "Ecology Update: Indiana Bat (Myotis sodalis)": "The USFWS has taken this finding to mean that north Georgia is likely within the summer range, and that we need to begin considering project's potential effects on ibat [Indiana bat]. This goes into effect immediately."

This announcement provided GDOT ecologists and its consultants with a preliminary map depicting the regulator's best guess as to where Indiana Bats' range spread as well as basic instructions about how to look for them within that range. GDOT explicitly expressed that these instructions were not final and would be improved later through *iterative management*. The designer of the draft range map had very little information about how far the species actually spread; his map was an exercise in educated guesswork.

Fri, 29 Jun 2012 21:09:46 "Ecology Update: Indiana Bat (Myotis sodalis)": "For now, the ibat should be considered in all of the counties within the proposed range, but keep in mind that this is just a draft range that may change. I know he struggled to define the range, given that so little is known."

GDOT never intended their procedures or range maps to be static; they were considered rough drafts which would be refined as more was learned about bats. At that point, GDOT relied heavily on procedures developed by other SDOTs from states where Indiana Bats are commonly found, but it always intended to create a specialized procedure for its own context. Compliant with AM, an initial decision was put in place and treated as a hypothesis about how Indiana Bats ought to be dealt within Georgia. It was intended to yield the best result given the limited information available at the time, but it was designed to be flexible to new information should it arise.

The consultants doing field work on bat-related projects were expected to carry out these procedures as GDOT agents, but they were also relied upon as monitors for how well those procedures were working at the project level. As the consultants learned about where Indiana Bats were and how to deal with them in the field they transmitted information back to GDOT which adapted its procedures and maps accordingly. This feedback allowed GDOT to test the hypotheses (i.e. bat range, survey practices, and procedural guidelines) it developed during the *goal-determination* phase and revise them over time through *iterative management*. Each GDOT project can be seen as a single iteration of environmental management. GDOT decisions made during the *goal determination* phase inform its staff and consultants about how to deal with bats at the project-level within each specific site's ecological context. The monitoring and feedback consultants provide at the project level generates knowledge which GDOT can use to update or revise its guidelines in coordination with federal regulators.

As indicated by GDOT staff interviews, the ecological consultants were able to provide some key information about Indiana Bats by surveying for them within the initial range ascribed to that species. The consultants found that bats were not in many of the places they expected them to be. Even though the environmental regulatory agencies had established a range and were considering expanding it GDOT used evidence from the consultants' field work to explain why that should not be done. As early as July 10th, 2012 this information was used to refine the range map being used and procedures for making bat surveys more precise were developed. Then on July 26th a full second draft of the map was published which improved the bat ranges even more.

Thu, 26 Jul 2012 18:48:02 "Ecology Update: Indiana Bat (Myotis sodalis)": "Indiana bat update: FWS has revised the draft range map. The new map does not change the proposed 'netting' area (cross-hatched), but expands slightly on the summer range (heavy red border) to include the entirety of any county touched."

This pattern of behavior indicates multi-level participation in dynamic learning. GDOT goals were revised as learning was generated through *iterative management* of individual projects. In order to facilitate this process, GDOT actively requested feedback from its consultants. The technical observations consultants made while in the field proved invaluable for both GDOT and the federal regulators. This learning allowed GDOT to improve its *adaptive performance* by absorbing the shock of the Indiana Bat discovery.

The regulations being implemented were never up for debate. GDOT, as well as the consultants working for it, had to comply. In this way, the overarching goals at stake (i.e. preservation of the endangered bat species being dealt with) were not included in the state level *goal determination* process. This process only included how best to achieve those overarching goals within the context of a new state. However, GDOT was given leeway within the overall command and control structure to adapt to the regulatory policies within its own context. Broad rules about what needed to be done were handed down through an authoritative hierarchy, but the rulemaking agencies relied on bottom-up feedback and technical advice from GDOT and its consultants to inform how those goals should be accomplished. The regulators were not simply mandating requirements for GDOT but were relying on its input in order to determine what to do. GDOT itself had the same relationship with its consultants. Each institution relied on feedback and technical learning from the group that was responsible to it in order to learn about the environmental problem.

Tue, 18 Dec 2012 22:10:08 "Gray Bat Section 7 *Range": "Coordination with NEPA staff about the requirements is also recommended so that FHWA does not receive documents that we cannot approve [because of inconsistencies with the ecology report]."*

At the same time, many consulting firms GDOT uses scrambled to catch up to the new bat regulations by acquiring the certifications and permits required to conduct surveys on endangered species. Many firms acquired these certifications after the ESA regulations came into effect since they were never needed before. At the outset of the case study, the incidence of endangered bat species was so rare few consulting engineering firms had the necessary certifications to conduct the analysis. However, by its end (a five-year window), both GDOT and its consultants had adapted to monitoring multiple species.

4.2. Adaptive Management and performance

The primary goals for an SDOT infrastructure project are associated with meeting transportation needs while performing the project on schedule and on budget. However, each infrastructure project must also comply with the NEPA process requiring environmental studies of air, water, and noise pollution, ecological impacts on habitat and species, as well as cultural and historic conditions associated with a site (Bass et al., 2001; Eccleston, 1999). The nature of the environmental review can have a profound effect on the intensity of the negotiations, and the levels of collaboration and conflict that take place during the project's *goal determination* phase. This, in turn, shapes the length of time taken to design and build an infrastructure asset for a state government. The goals prescribed for each state transportation project are heavily shaped by the agency's interaction with federal and state regulatory authorities who are the primary source of guidance for environmental compliance.

The first *adaptive event*, the discovery of Indiana bats, had a substantial impact on project performance. It required a steep learning curve for GDOT agents who had to determine how to address the new regulations despite not knowing exactly how they would work within the state's unique ecological context, find the best way to figure out how far the species' range extended, and then decide how best to communicate guidance to the consultants who would be doing the work required for compliance in the field. GDOT generated the knowledge necessary to overcome the learning curve associated with Indiana Bats opportunistically through its consultants' experience in the field. Rather than setting aside a subset of affected projects to experiment on, it relied on project-level variation experienced by its consultants to produce knowledge about how best to deal with the new bats. In addition, GDOT and consulting ecologists had to scramble to learn, and get certified for, the various surveying and monitoring techniques that the new regulations required.

In the statistical analysis embedded within our case study, we regress environmental review duration on two multivariate models to analyze the impact of the two adaptive events and assess GDOT's *adaptive performance.* The results are included in Table 3. As depicted in model 1, the environmental review process took significantly longer to complete for projects which had to deal with the first *adaptive event,* the introduction of Indiana Bats. They required about 766 additional days for completion.

Table 3
Regression Results. Output for two multivariate models assessing the impact of each adaptive event.

n	81		81	
R-squared	0.3524		0.3168	
Variables	Model 1		Model 2	
Environmental Review Duration	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Indiana Bat	765.69**	368.567	–	–
Gray Bat	–	–	226.26	392.218
Lead Time	−1.18**	0.589	−1.37**	0.601
Bridge Replacement	−629.85	657.028	−515.87	673.477
EA	1744.01***	443.947	1666.86***	455.357
State Sponsor	−480.59	323.421	−436.10	331.786
Experienced PM	−433.89	349.768	−359.61	360.144
Experienced NEPA Analyst	248.04	251.122	281.01	258.716
Experienced Ecologist	358.75	272.867	296.37	280.267
Constant	2070.69***	777.372	2536.92*	1429.014

***p < 0.01, ** p < 0.05, *p < 0.1.

When the shock first took place GDOT was unsure about how to deal with it. Some projects were impacted much more seriously than others making it difficult to predict where delays might take place. This was exacerbated by the set of new certifications and necessary skills required for consultants to deal with endangered bats in the field. Many of GDOT's consultants had to update their certifications and staff training before proceeding with their project or resolve how to integrate a certified firm as a sub-contractor. Until the technical expertise was in place, GDOT projects would have to be put on hold, delaying them until consultants met the requirements necessary to complete their surveys.

However, GDOT reduced this uncertainty by engaging in adaptation over iterative decisions as consultants tested their efficacy in the field. We learned from GDOT staff and consultant interviews that consultants cooperated with both GDOT and federal regulatory agencies directly. This cooperation facilitated learning about bats because it gave state and federal agencies access to project-level knowledge. This enabled GDOT to refine its management strategies over time and increase its performance by reacting to the shock and absorbing some of the disruption it had initially caused. Over time, project review durations gradually became shorter again as the shock became further removed and more was learned about the new species of bat.

We study the *adaptive performance* of GDOT by examining whether its *iterative management* resulted in decreased environmental review durations over time. The regression results show a significant decrease in project durations as lead time increases showing adaptation taking place. In this sample, projects were completed about 1.2 days faster for each additional day GDOT had available to adapt before starting. The strength of these results is limited by the small number of observations in our study and the large standard errors of many of the parameter estimates in our model, but they support the narrative from our qualitative analysis. This evidence indicates that adaptation was taking place at GDOT.

Six months after the discovery of Indiana Bats, a second species of bat, the Gray Bat (myotis grisescnes), was detected in north Georgia. This species is also endangered and resulted in a second *adaptive event* for GDOT. Gray Bats have been listed as endangered since 1976 and require compliance to the same set of regulations as Indiana Bats (ESA, 1973). This species is different from the first endangered species of bat encountered by GDOT in that it prefers roosting in caves rather than trees and occupies a distinct geographical region from the Indiana Bat, even though the two ranges overlap considerably (USFWS, 2017). However, this *adaptive event* was much easier for GDOT to deal with because so much of the learning and technical expertise they had acquired dealing with Indiana Bats was transferable to this new species.

We ran a second OLS model, also included in Table 3, to measure the impact of the second *adaptive event* (Gray Bats) and gauge the *adaptive performance* of GDOT by comparing it to the first *adaptive event* (Indiana Bats). The coefficient for the second event's interruption is positive, showing that this set of interrupted projects was delayed by about 226 days, but it is not statistically significant. This supports the narrative originating from our qualitative analysis because it shows that the second shock was much less disruptive than its precursor. The resulting delay was much smaller than that of the first shock and was statistically insignificant meaning that we cannot be confident that the second shock disrupted project timelines at all. GDOT was able to minimize the disruption of the second *adaptive event* it experienced due to learning it gained through AM.

As shown by staff interviews, GDOT engaged in another phase of *goal determination* through discussion with regulators and consultants about Gray Bats, but they were able to quickly arrive at a conclusion by applying their previous learning to the new case. Additionally, many of the consultants responsible for surveying for this new species already had the skills and certifications in place to deal with bats under the ESA resulting in fewer delays. GDOT had a much easier learning curve during this second *adaptive event* because the iterations of procedural refinement it had already gone through for the Indiana Bat served as preparation.

4.3. Generating learning through Adaptive Management

Although not yet protected by ESA regulations, GDOT then began paying more attention to other native bats listed as threatened or species of concern. Finding new bats, in tandem with the incursion of WNS into Georgia, put GDOT on alert for local species. This ushered in yet another *adaptive event* related to bats for GDOT to deal with.

In January of 2013 the USFWS published a set of procedures for dealing with Indiana Bats across their entire US range. GDOT now had to factor this additional set of guidelines in on their projects. These procedures were set at the federal level and not open to change. However, GDOT continued learning about bats and tweaking its own procedures (within the overall structure of the federal guidelines) well past the date the national guidelines were instituted. At GDOT, consultants continued to monitor Georgian bats, and the procedures used to deal with them, providing feedback to GDOT on a project by project basis. GDOT, in turn, continued to improve its bat-related procedures in an iterative fashion. This continued until the end of the time period we observe in 2015 when GDOT published a new template triggering data collection on bats anytime a bridge was present on one of its project sites. Even after universal federal regulations were put in place, GDOT continued adapting to bats within its own state context, refining its procedures as necessary through *iterative management*.

GDOT was able to learn how to meet the standards of newly implemented federal regulations more effectively by implementing an initial strategy and revising it over time in response to feedback from its consultants. This strategy also enabled it to efficiently apply previous techniques to other threatened bat species. Continued field monitoring by consultants enabled GDOT to assess and refine its management decisions. The contracting structure of the agency-consultant relationship did not dictate independent monitoring of bats, but the normal job activities they conducted (e.g. ecological studies and field surveys) necessitated the continued monitoring of at-risk counties within the agency's jurisdiction. This situation presented an opportunity to observe AM. GDOT's use of historical data, hypothesis forming, and iterative learning to assess its projects show reliance on consultants to facilitate knowledge generation, but that it still engaged in an adaptive process, unlike traditional bureaucratic procedures. The more experience GDOT acquired with bats and time it had available to adapt, the more expediently it was able to fulfill the expectations of the new regulations and complete its environmental reviews. Over time GDOT minimized the shock of the regulatory change by cooperatively learning and refining the management methods it employed.

5. Discussion

GDOT acted as AM predicts, but it did so in a slightly different way than we expected. It engaged in three-tiered collaboration within a largely authoritarian structure. Even though the consultants are subordinate to GDOT, and GDOT is subordinate to the environmental regulatory agencies, they all collaborated together in order to successfully adapt to the introduction of bats. Consultants at GDOT fulfill three different roles. First, they serve as GDOT agents, satisfying their direct contractual obligations. Second, they act as environmental specialists who generate learning through their experience at the project level. Finally, they act as intermediaries between GDOT and other public agencies, federal regulators, research and environmental groups, and local stakeholders. GDOT is not a collaboratively governed organization. It maintains a principle-agent relationship with its consultants and retains the hierarchical structure of most traditional bureaucracies. However, it exercises discretion in how it applies this hierarchy within the decision-making process, incorporating elements of collaborative governance in order to facilitate adaptive learning. GDOT's consultants broker communication between GDOT and other public and private stakeholders, giving them a say in how environmental issues are addressed. GDOT maintains enough lateral flexibility within a vertically structured government system to manage environmental subjects using AM.

As AM suggests, there was internal discussion within GDOT; there were also simultaneous channels of top-down and bottom-up communication. Federal regulatory agencies mandated requirements for GDOT, but they also allowed feedback from GDOT to inform them about what practices were best suited to fulfill their requirements. GDOT acted the same way with its consultants. It mandated procedures but relied on consultants' input to help revise them. In addition, consultants regularly engaged in discussion with the environmental regulatory agencies themselves. They were not limited to communicating with GDOT. They often went to the source and discussed the regulations they were required to follow directly with the regulatory agencies. The consulting community itself engaged in market adaptation, leading to a complex network of relationships between consulting firms regarding the regulatory issue. Some firms chose to specialize in the new changes, immersing themselves as experts and mediators in GDOT's adaptive process, while others chose to defer, subcontracting out related work to firms which had already gained specialization. We do not see strict internal discussion or adherence to the principle-agent hierarchy between the federal regulatory agencies, GDOT, and consultants, or uniform action being taken by all consultants. Instead, we see multi-tiered collaboration where what must be done is dictated in a top-down structure, but how it should be done is informed through a bottom-up approach. This is enabled by GDOT consultants who opted to immerse themselves in the adaptive process to act as mediating agents by bridging communication between GDOT and regulatory agencies. They provided the horizontal flexibility necessary to successfully adapt to the bat-induced regulatory shock within a vertically aligned system. This structure is modelled in Fig. 4.

The multi-tiered collaboration structure enabled GDOT to engage in AM. GDOT itself remained passive, choosing not to set aside a portfolio of projects to experiment on explicitly. However, it was able to learn about bats through collaboration with consultants who were gathering knowledge through iterative interactions, and natural experimentation, with bats at the project level. This coordination allows GDOT to learn about complex environmental problems and successfully adapt to the changing environment over time.

The relationships between managers and consultants are not well explained in the AM literature. These relationships are often present in environmental management situations, but they are not explicitly described in AM models. How they fit into the adaptive process needs to be addressed in order to better our understanding of how AM can function within a bureaucratic system. When NPM and collaborative practices lead a bureaucracy to engage with private consultants, it can have the flexibility necessary to collaborate with multiple actors and generate knowledge through AM. This can allow organizations to achieve better management outcomes within the context of a top-down, authoritarian system. We build off the existing AM model (Fig. 1) by incorporating the multi-tiered collaboration system we observe in our analysis into the process. See Fig. 5.

This understanding may encourage the use of AM in bureaucratic organizations through outsourcing. Institutions which do not traditionally employ adaptive strategies might try to capture the benefits adaptation provides through the third-party actors they outsource to. Today, conservation decisions are often based on experience rather than real evidence, undermining practitioners' ability to make effective conservation decisions (Pullin and Knight, 2001). Sutherland et al. (2004) stress that the need for evidence-based conservation is critical; structures which incorporate systematic monitoring and review into the

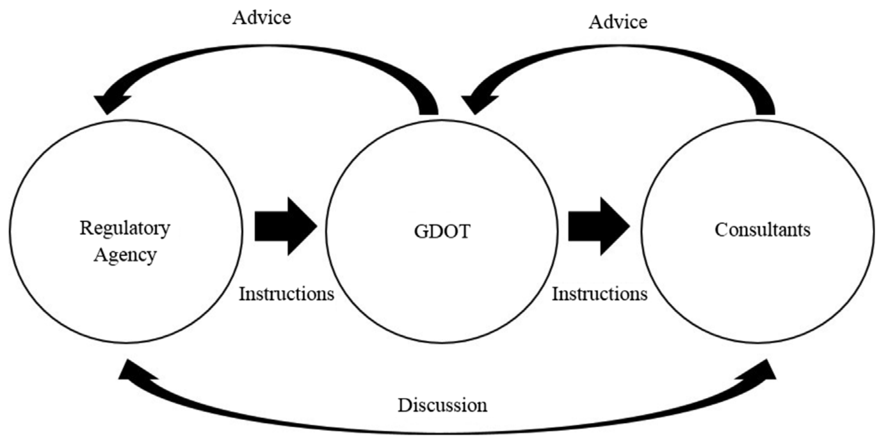

Fig. 4. Multi-tiered Collaboration. Collaborative architecture at GDOT.

decision-making process are crucial for environmental managers to make effective choices. The adaptive structure we observe at GDOT is one way for evidence-based decision-making to be integrated into the management process within a bureaucratic organization.

6. Conclusion

We observe adaptive practices occurring at two levels. First, we find that when GDOT encountered environmental shocks it shifted towards a more adaptive approach, relying on consultants to gather information from individual infrastructure projects in a manner that resembles iterative experimentation. GDOT's goals were to learn about environmental conditions as well as to develop new standardized procedures and guidance that could be applied to future projects. In the face of shocks, GDOT moved to an adaptive posture and then sought to establish new standard operating procedures (i.e. bureaucratic processes) once the shocks were absorbed. Environmental consultants provided important information from the field that facilitated this learning process. We also identify a second adaptive process that spans both periods of shock and periods of normal operations. GDOT relied on consultants as a matter of routine to facilitate adaptive changes in management strategy over time.

GDOT's organizational structure allows it to engage in multi-tiered collaboration, knowledge generation, and adaptation through AM. The more time GDOT had available to learn and adapt to the regulatory shock, the more successfully it was able to manage the environmental review of its projects. Environmental review durations significantly decrease the more time is available to GDOT for adaptation even after controlling for project type, NEPA classification, funding source, and staff experience.

However, there are several limitations to this study. Our results are constrained due to a limitation in the nature of our dataset. Projects do not enter our dataset until they are completed so there is a sampling bias present at the end of the time window our dataset represents. While complex projects requiring long periods of time to complete are included in our dataset if they began very early (their having been completed within the data collection window), projects which were in progress, but were not yet completed before the end of the data collection window are absent. This means that the subset of projects in our dataset which started late in the data collection window will likely have a higher proportion of projects with short durations than the rest of the dataset. Many complex projects requiring longer durations were ongoing at the time, but if they didn't finish before the data were compiled they were not included. This potentially biases our results. However, the story our results illustrate is generally compliant with our qualitative analysis.

Second, due to the construction of our dataset, as noted above, and the quick succession of the first and second *adaptive events*, there is substantial overlap between the shocks for Indiana and Gray Bats. Many of the interrupted projects we observe were impacted by both events. Out of the 11 projects interrupted by Indiana Bats, nine were also interrupted by the subsequent Gray Bat shock. There are only two and one total projects uniquely interrupted by the Indiana and Gray Bat shocks respectively. The addition of the Gray Bat shock could have contributed to additional time disruption for projects already shocked by the Indiana Bat event. Performance data indicates that this may not be the case as environmental review durations were not longer for projects interrupted by both *adaptive events* than for those uniquely

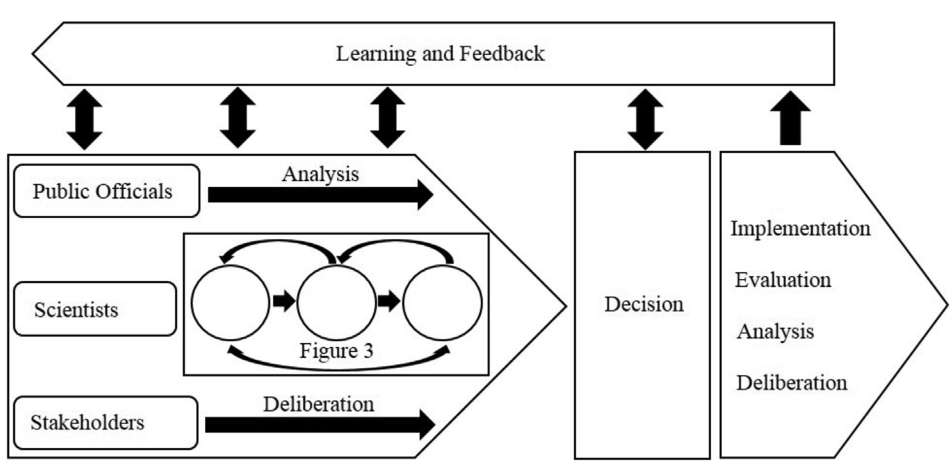

Fig. 5. Improved Adaptive Management Model. AM model including a multi-tiered collaboration system.

interrupted by the first event, but this remains an area of concern.

Future research on this subject using a more complete set of performance data across mutually exclusive *adaptive events* would be useful to help clarify these issues. More robust statistical tests are needed to estimate the impact of the adaptation organizations like GDOT engage in. Furthermore, additional research using Bayesian methods may enrich our results. Bayesian network models provide a statistically sound framework to integrate qualitative and quantitative information from diverse sources, and explicitly model uncertainty (Barton et al., 2012; McCann et al., 2006; Pearl, 1988), making them extremely relevant to this type of research question. Future research using this approach could account for uncertainty and other interactive effects which would help increase our understanding of how feedback routes function in the adaptive process.

This study points to AM as an effective method of internalizing environmental shocks under uncertainty, stabilizing the situation around them and allowing a return to normal operations where projects can be completed in a similar amount of time to how long they took before the shocks occurred. In addition, it indicates that multi-partner collaboration can be a successful strategy for integrating dynamic learning into the management process. The multi-level communication structure implemented by GDOT is a strong format for applying AM. We build on existing models to explain how multiple partners and mediating actors collaborate in order to successfully achieve AM goals.

Data statement

We are unable to provide the data we use for publication between confidentiality and GDOT data security restrictions prevent us from doing so. The qualitative data we use include sensitive materials which will not be released in order to preserve the confidentiality of research respondents. The quantitative dataset we use is proprietary, and we do not have permission to release it.

Conflicts of interest

None.

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