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Measuring Administrative Friction: A Transaction-Cost Framework for Sludge Audits

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Abstract
Sludge–those excessive frictions that slow or distort administrative processes–has become a central concern in Behavioural Public Administration, yet existing definitions and audit models remain conceptually vague and difficult to operationalize. Building on the literature on heuristics, biases, and transaction costs, this paper proposes a more precise and generalizable framework for identifying and measuring sludge within public organizations. After clarifying its relationship with related concepts such as ordeal mechanisms, red tape, and administrative burden, the paper connects sludge to the classic typology of transaction costs, expanding it with an additional category of red-tape costs. It then introduces a new Sludge Audit Model that decomposes processes into measurable sub-actions, quantifies time, direct costs, psychological costs, and opportunity costs, and identifies which steps can be simplified, digitized, or eliminated without reducing efficiency. The model aims to provide public administrations with a practical and scalable tool to diagnose frictions and prioritize interventions that improve administrative effectiveness.

JEL Classification: D73; H11; D91; D02; D23

Keywords
behavioural public administration — sludge — transaction costs

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Introduction

Discussions regarding the foundations of public administration, including the connection between public administration and psychology, can be traced back to the 50s and 70s when Herbert Simon and Dwight Waldo emphasized the significance of psychological research in the study of public administration. Even Dahl stated that a science of public administration must be based on a "knowledge of man's behavior in the area set off by the borders of public administration" (Dahl, 1947). Around 2007, there was a considerable shift from qualitative to quantitative work (McDonald et al., 2022), and in 2017, has been defined the term Behavioral Public Administration (BPA) as "the analysis of public administration from the micro-level perspective of individual behavior and attitudes by drawing on insights from psychology on the behavior of individuals and groups" (Grimmelikhuijsen and Porumbescu, 2017). However, despite these early calls to integrate the two fields, public administration scholars have partly neglected theories and methods from psychology (Jones, 2003; McDonald et al., 2022).

BPA is not limited to academic study, but it has also undergone a recent evolution within government administrations. The Cabinet Office in the United Kingdom and the White House Social and Behavioral Sciences Team in the United States are notable examples (Grimmelikhuijsen and Porumbescu, 2017).

BPA scholars have focused on public administration employees because working in behavioral public administration involves examining the micro-foundations of the theories that inform public administration (Grimmelikhuijsen and Porumbescu, 2017). The focus has been mainly on studying heuristics, biases, and nudges. Through heuristics that guide public managers in ways that yield more favorable results, behavior modification techniques offer a deeper understanding of how we can influence decision-making by nudging public managers in ways that lead to more favorable outcomes (Battaglio et al., 2019).

Even if BPA represents a significant evolution for institutions (or, we might say, a rediscovered interest), it represents a shift toward methodological plurality and exponential growth in its openness to interdisciplinary approaches (McDonald et al., 2022). It also faces important limitations. As Muramatsu and Barbieri (2017) observe, policymakers operate under fundamental epistemic constraints that limit the predictability of behavioral interventions. This reality underscores the need for systematic, evidence-based frameworks–such as the transaction-cost approach to sludge audits proposed here–that make trade-offs explicit and acknowledge the boundaries of administrative optimization.

The remaining open scenarios that require further investigation include how micro, meso, and macro viewpoints are interconnected and how behavioral policies are shaped by and influence such a condensed view of the policymaking process

(Ewert et al., 2021). Following Hayek (1952), the challenge of behavioral economics lies in explaining why objectively similar events are perceived and processed differently by individuals.

Behavioral Public Administration, given its micro-foundations, draws its main inspiration from the work of Herbert Simon on bounded rationality (Simon, 1955, 1997), which has been further developed in the study of heuristics and biases (Gigerenzer and Selten, 2001; Kahneman, 2011). Human beings use various mental tools (heuristics) to carry out their actions. Bounded rationality (as representation) provides an appropriate framework for economic theories in which the outcome of a decision can't be predicted without first understanding the underlying processes (Simon, 2000). Bounded rationality is expressed through heuristics.

A heuristic is a basic mental shortcut that helps find "sufficient, though frequently imperfect, answers to tough situations" (Kahneman and Tversky, 1982). It is utilized intuitively, simplifying and facilitating decision-making (Kahneman and Tversky, 1972; Thaler and Sunstein, 2021). Heuristics aren't always erroneous; they can help generate precise and appropriate conclusions and are often effective in developing efficiencies and lowering complexity (Tversky and Kahneman, 1974). When heuristics lead to systematic deviations from the ideal or reasonable course of action, a cognitive bias is born (Moseley and Thomann, 2021).

A cognitive bias is a pattern of judgmental divergence from the norm or rationality. Individuals develop their "subjective reality" based on how they perceive the information. It is possible that an individual's perception of reality, rather than objective input, determines their conduct in the world (Kahneman and Tversky, 1972). As a result, cognitive biases can occasionally cause visual distortion, incorrect judgment, illogical interpretation, or irrationality (Kahneman and Tversky, 1972). Utilizing a more informed assessment of cognitive biases and libertarian paternalism to influence public managers' decision-making processes has the potential to enhance effectiveness through strategic decisions that determine goal attainment (Battaglio et al., 2019). When a bias leads to a slowdown or friction in a decision-making process, we speak of sludge: "excessive or unjustified frictions that make it difficult for consumers, employees, employers, students, patients, clients, small businesses, and many others to get what they want or to do as they wish" (Sunstein, 2020). If we consider it briefly, there are many biases that can influence processes in public administrations. Above all, one is the status quo bias. When faced with options involving the current system, status quo bias refers to the tendency to continue with the current option, especially in uncertain situations (Samuelson and Zeckhauser, 1988). This concept is based on people's tendency to stick to their routines rather than adapting to new situations (Oschinsky et al., 2021). This phenomenon reflects a desire to maintain the status quo, avoid anxiety-inducing conflict, and ignore reality (Diamond, 1985).

More generally speaking, recent work in behavioral public administration has emphasized the role of heuristics as both adaptive tools and potential sources of bias in policy design (Mousavi, 2018; Sunstein, 2018). To address these issues, we present a new Sludge Audit Model that breaks down processes into quantifiable sub-actions, measures time, direct costs, psychological costs, and opportunity costs, and identifies steps that may be streamlined, digitized, or removed without compromising productivity.

Analytical Framework

Paraphrasing Hayek, mainstream economics aims to substitute an objective classification for the subjective classification that our senses make of occurrences. The challenge of behavioral economics is to explain why these events, which can be arranged in a particular sequence based on their relationships to one another, materialize in a different order when they impact our senses[1]. So, the issues with conventional economics stem from the reality that events that seem similar to us do not always behave similarly to other subjects (Hayek, 1952).

While the connection between heuristics, biases, and sludge may seem intuitive, the precise causal mechanism deserves explicit articulation. Public administrators, operating under bounded rationality, rely on heuristics when designing administrative processes. Common heuristics include the availability heuristic, such as designing safeguards based on memorable cases of fraud or error, even if they are statistically rare. Representativeness heuristic that assumes all citizens fit the "typical case," ignoring heterogeneity in needs and capabilities. Anchoring, that is, preserving existing procedural steps because they serve as anchors, even when circumstances change.

These heuristics constitute adaptive responses to administrative complexity, but they introduce systematic patterns into process design. While heuristics are often framed negatively as sources of bias, recent research suggests they can also serve as effective decision tools in complex policy environments (Mousavi, 2018). The dual nature of heuristics–as both adaptive mechanisms and potential sources of friction–underlies our framework for identifying sludge.

In fact, when heuristics consistently lead to deviations from optimal process design, they manifest as cognitive biases. The most consequential for sludge generation is status quo bias – the tendency to prefer existing procedures over alternatives, especially in uncertain situations (Samuelson and Zeckhauser, 1988).

Status quo bias operates through multiple psychological mechanisms. Changing a procedure creates perceived risk of criticism if problems arise, while maintaining it incurs no blame (loss aversion). Reforming processes requires effort; maintaining them requires none (in the form of transition costs). Harms caused by inaction (sludge persisting) feel less blameworthy than harms caused by action (omission bias). Multiple stakeholders must agree to change; maintaining the status quo requires no consensus (coordination challenges).

[1] Hayek refers to the problem as physical sciences and theoretical psychology.

Sludge emerges when biased decision-making produces excessive or unjustified friction – costs imposed on citizens, employees, or businesses that exceed the benefits of the procedural requirement (Sunstein, 2020).

However, not all friction is sludge. Identity verification to prevent fraud imposes costs, but these are proportionate to the risk being mitigated, and are a justified friction. While requiring in-person submission of documents that could be submitted electronically imposes costs without commensurate benefit is an unjustified friction (sludge). Sludge, then, is the *residual friction* that persists due to cognitive biases rather than rational cost-benefit analysis.

Critically, sludge is self-reinforcing through multiple mechanisms. First, it is often invisible to designers, as administrators who created a process rarely experience it as citizens do, generating an empathy gap. Second, the costs of sludge are widely distributed while the benefits of maintaining it are concentrated: each instance imposes small burdens on many citizens, but removing it requires concentrated effort by a few administrators. Third, status quo bias recurs through the system, so even when sludge is recognized, reform is inhibited by the mentality of "we've always done it this way." Finally, citizens often develop defensive adaptations, such as hiring consultants or using intermediaries, which mask the true costs and reduce the pressure for reform. As Briscese et al. (2023) demonstrate, citizens often misperceive administrative burdens as social norms ("everyone goes through this"), leading them to use heuristics that rationalize rather than challenge existing friction. When excessive procedures become normalized, citizens may fail to recognize them as eliminable sludge, further entrenching inefficiency.

These mechanisms generate a ratchet effect, in which procedures are easily added but rarely removed, leading to cumulative administrative accretion. This, in turn, underscores the importance of conducting systematic sludge audits.

Conducting such audits effectively requires several considerations. Frontline workers should be included, as they experience citizens' friction firsthand and can identify empathy gaps. Every step of a procedure should be questioned, since status quo bias often leads to the defense of "we've always done it this way" without justification. Hidden costs, including opportunity costs and psychological burdens, should be quantified to make them visible to designers who might otherwise overlook them. External auditors are valuable because internal staff, being subject to the same biases that created sludge, may not recognize it. Finally, documenting removal experiments – testing whether eliminating steps causes problems – provides concrete evidence to challenge status quo bias.

Thus, sludge auditing is not merely a measurement, but a debiasing intervention – a structured process to counteract the cognitive biases that generate and perpetuate excessive friction in administrative systems.

Public administration can be conceptualized as a system subject to friction, analogous to resistance forces in physical systems. In physics, moving such an object activates friction – a force that opposes motion relative to the surface. This friction is governed by Coulomb's law: $F_f \leq \mu F_n$, where μ is the coefficient of friction and F_n is the normal force (Halliday et al., 2013).

Civil servants, attempting to move this "administrative solid," apply a shear force. From a purely external perspective – treating the administration as a black box – we might observe only that movement is difficult without understanding why. The friction coefficient μ appears as a given property of the system.

However, when we open the black box and examine its internal structure, we discover that friction is not a monolithic force but rather the cumulative effect of multiple internal components interacting with each other and with the surface. Some components are necessary – they provide stability and prevent chaotic, uncontrolled movement. Others are unnecessary obstructions – rough edges, misaligned parts, and accumulated debris – that increase resistance without serving any structural purpose.

Sludge auditing can therefore be understood as an optimization problem: reducing unnecessary transaction costs while preserving functionally necessary components.

This analogy clarifies why simply measuring total time or cost is insufficient. A process that takes 10 hours might have a low coefficient of friction (indicating necessary complexity) or a high one (suggesting excessive sludge). Only by examining the internal structure – the specific transaction costs at each step – can we distinguish between them and target interventions appropriately.

Moreover, the analogy reveals why crude elimination of steps is risky: removing load-bearing components to reduce friction will cause system failure. The elimination threshold criterion we propose ($\Delta(TC + OC) - \Delta E > 0$) is precisely the test that separates unnecessary rough edges from structural necessities.

Defining the problem

In the current line of the research described above, different terms are used to indicate the same phenomena often, and as pointed out by Madsen et al.: "[The] combination of overlap and substantive differences may cause researchers studying quite different phenomena to be incorrectly grouped, and it may cause researchers studying similar phenomena to fail to communicate or to set up rival camps rather than coordinating efforts and learning from one another" (Madsen et al., 2022).

Historically speaking (Madsen et al., 2022), the concept of ordeal mechanisms was first introduced in the early 1980s, followed by the red tape resulting from empirical studies in the early 1990s, then by administrative burden (2019) and sludge (2018). On the other hand, identifying these distinct pieces does not imply placing a single definition that varies depending on the object under consideration (Madsen et al., 2022). However, since this is not a thorough evaluation of these definitions, we will adopt the most relevant definitions for our purpose.

1. Ordeal mechanism: "The imposition of deadweight costs to qualify for a transfer" (Nichols and Zeckhauser, 1982).

2. Red tape: "Rules, regulations, and procedures that remain in force and entail a compliance burden for the organization but have no efficacy for the rules' functional object" (Bozeman, 1993).

3. Administrative burden: "Interactions with the government that impose (or lessen) burdens on individuals and organizations" (Heinrich, 2018).

4. Sludge: "It is the form of excessive or unjustified frictions that make it difficult for consumers, employees, employers, students, patients, clients, small businesses, and many others to get what they want or to do as they wish" (Sunstein, 2020).

Sludge's definition is too vague to measure "sludge". Using the transaction cost theory (Williamson, 1989), a more precise definition can be "aspects of the choice architecture that lead to the experience of costs or charges that must be paid for an action to take place, but which may or may not provide any value to the person who pays the expense" (Shahab and Lades, 2021).

Starting from this last definition, we can highlight the connection between BPA and transaction costs theory, and how this represents the contact point with economics. The problem is always to understand "to what degree are transaction-specific (non-marketable) expenses incurred" (Williamson, 1981).

Shahab and Lades (2021) have attempted to connect sludge and transaction costs. They identify four types of costs: search, evaluation, implementation, and psychological. This approach provides an initial theoretical bridge between sludge and transaction cost economics, relying on the Dahlman (Dahl, 1947) typology of transaction costs, even if the original distinction was designed for the application of market transactions. However, another necessary type of cost is missing: red-tape costs, defined as aspects of the choice architecture that lead to evaluation costs due to excessive, rigid, or redundant regulations that obstruct or prohibit action or decision-making.

Starting from here, we will build the proposed model.

Sludge audit

Shahab and Lades (2021) proposed an audit model in five phases: (1) Breaking up the processes into required actions; (2) Choosing the appropriate method; (3) Recruiting the relevant participants; (4) Asking the right questions; (5) Communicating the benefits of sludge audits.

This model outlines clear procedural steps for conducting a sludge audit, emphasizing stakeholder involvement through participant recruitment and recognizing the importance of effective communication in the implementation process.

However, the model offers no specific metrics for measuring sludge intensity or comparing different friction points. Each phase requires substantial customization for different organizational contexts, which risks inconsistent application. While the authors identify four types of transaction costs (search, evaluation, implementation, and psychological), they do not systematically integrate these into the audit process. Moreover, the model does not specify how to prioritize which sludge to address first or what threshold determines whether friction is excessive.

Without clear metrics and decision criteria, sludge audits risk replicating the very frictions they are intended to reduce.

Some public organizations have begun implementing Sludge Audits to assess the impact of various activities. For example, the Pakistan Institute of Development Economics (PIDE) has made a measurement effort by estimating the time consumed in executing the activity and the costs (processing cost and opportunity cost) involved in executing it. For each considered activity (obtaining different concessions; buying and selling a lot; opening different businesses; hiring employees; obtaining an exchange license; investigating the pension system), the following elements have been considered: time consumed, agency time, overhead time, costs (processing cost, opportunity cost), stress (Pakistan Institute of Development Economics, 2022).

The model offers an empirical grounding, measuring actual processes with real data. It provides concrete recommendations (digitization and elimination) and considers both objective (time and costs) and subjective (stress) factors, making calculations and assumptions explicit.

However, it assumes all hours lost have equal value, ignoring that opportunity costs vary by time of day (peak business hours vs. off-hours), individual circumstances (employed vs. unemployed citizens), process criticality (time-sensitive vs. routine procedures), and substitution possibilities (whether the person could multitask or delegate). Moreover, using average wages assumes that lost time equals lost earning potential, which fails to account for salaried workers who don't lose income during administrative tasks, retirees, or students with zero wage-based opportunity cost and high-value activities beyond wage work (childcare, education, health). The model doesn't capture how sludge in one process creates ripple effects (e.g., missing a business deadline, delayed medical treatment).

Our proposed model addresses these limitations by providing a more rigorous and generalizable framework grounded in transaction cost economics.

An Operational Transaction-Cost Framework

Complete Cost Typology

We expand Dahlman's transaction cost framework with a fifth category specifically relevant to public administration:

1. Search costs: Time and resources spent identifying requirements, locating offices, finding information, and understanding what is needed.

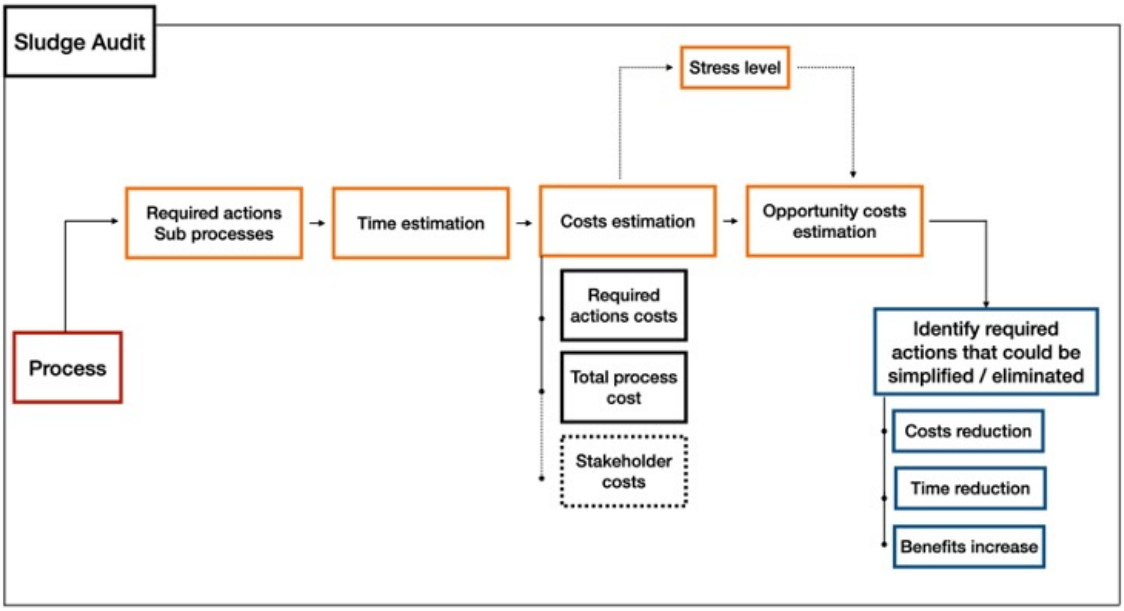

Figure 1. Sludge Audit Model: decomposition of administrative processes into transaction-cost components and decision criteria.

2. Evaluation costs: Cognitive effort to understand rules, assess compliance, interpret requirements, compare options.

3. Implementation costs: Direct expenses (fees, travel, materials) and time costs of executing required actions.

4. Psychological costs: Stress, anxiety, confusion, frustration, stigma, fear of errors.

5. Red-tape costs: Costs arising specifically from excessive, rigid, or redundant regulations that obstruct action—distinct from necessary compliance costs.

This categorization enables cost attribution: every identified friction point can be classified, allowing for the analysis of patterns. Rather than a single formula, we propose a context-sensitive approach to opportunity costs:

$$OC = f(T, V, S, C) \tag{1}$$

Where T is the time consumed, V is the value of time (varies by individual and context), S is substitutability (can the task be delegated, delayed, or combined?), and C is criticality (time-sensitivity of the administrative need).
Then, for employed individuals during working hours:

$$OC_{employed} = T \times \text{hourly wage} \times (1 + \text{urgency multiplier}) \tag{2}$$

For unemployed or retired individuals:

$$OC_{nonemployed} = T \times (\text{leisure value} + \text{search cost}) \tag{3}$$

For time-critical processes (e.g., medical emergencies, business deadlines):

$$OC_{critical} = T \times \text{hourly wage} \times \text{criticality factor} + \text{penalty costs} \tag{4}$$

This allows for sensitivity analysis: organizations can model how opportunity costs vary across different citizen segments and process urgencies. We introduce a three-part test for determining whether a process step constitutes an eliminable sludge:

Elimination Threshold: A sub-process or action should be simplified, digitized, or eliminated if:

$$(\text{Cost reduction} + \text{Time reduction}) > \text{Efficiency loss} \tag{5}$$

More formally:

$$\Delta(TC + OC) - \Delta E > 0 \tag{6}$$

Where ΔTC = Change in total transaction costs (search + evaluation + implementation + psychological + red-tape), ΔOC = Change in opportunity costs, and ΔE = Change in process efficiency (quality of outcome, error rate, compliance rate).

Efficiency is measured by several criteria, including the accuracy of outcomes, such as error rates before and after process changes; the degree of goal achievement, assessing whether the process still accomplishes its intended purpose; compliance rates, indicating whether citizens continue to meet requirements; and secondary effects, capturing any unintended consequences that may arise.

This criterion reduces the risk of eliminating steps that are costly yet functionally necessary.

Explicit Role of Implicit Knowledge

We acknowledge that sludge identification is partly experiential, as civil servants with deep process knowledge may recognize inefficiencies that are not immediately apparent from time or cost data alone. Our model incorporates this by including a qualitative assessment phase in which frontline workers identify suspected sludge, triangulating quantitative metrics with employee insights, and documenting tacit knowledge about workarounds, frequent errors, or citizen complaints. This mixed-methods approach ensures that the audit captures both measurable frictions and harder-to-quantify inefficiencies.

Scalability and Generalizability

Unlike Shahab and Lades' approach, which requires substantial customization, our model offers standardized metrics that can be applied across different processes and organizations, produces comparable outputs that enable benchmarking, and features a modular design allowing organizations to begin with time and cost analysis and progressively incorporate psychological and opportunity cost measurements as resources permit.

The model offered in this article takes inspiration from these contributions. While maintaining the four costs' classification plus the red-tape costs, a more precise and generalizable model will be offered to public administrations. The proposed model is made up of: (1) Split the process into required actions or sub-processes; (2) Estimate the expected time for each individual action or sub-process; (3) Estimate the costs: of the sub-process, the total cost of the process, the opportunity costs, and possibly the costs of other parties involved; (4) Estimate the level of stress if necessary; (5) Identify actions that can be simplified, digitalized, or eliminated from the process without changing efficiency. The process is described in Figure 1 that visualizes the five-step audit process as a decision tree. The process begins with decomposition (Step 1), flows through time and cost estimation (Steps 2-4), and culminates in the elimination decision (Step 5), which applies the threshold criterion (Equation 6) to determine whether each sub-process should be retained, modified, or removed.

The threshold for making this decision is partly influenced by the experiences of individuals. Realizing that a sub-process or action is a sludge is also related to the implicit knowledge of the employee. In general, the decision is given by three elements. The elimination of the chosen action must allow for a reduction in costs (and/or time) while simultaneously increasing the process's efficiency. Eliminating actions solely because they are time-consuming or expensive without considering their impact on the process's efficiency would lead to the risk of eliminating fundamental actions, ultimately making the whole process inefficient.

Discussion and Implications

The integration of transaction cost theory provides several advantages. Theoretical coherence is achieved by grounding sludge in established economic theory, which enables us to connect BPA to the broader institutional economics literature, facilitating cross-fertilization with research on market frictions, organizational design, and regulatory efficiency. Measurability because every friction point can be assigned to a cost category and quantified, enabling cross-process comparison, before/after evaluation of interventions, and cost-benefit analysis of sludge reduction initiatives. Cost attribution reveals patterns that guide targeted interventions. The red-tape cost category explicitly connects sludge to regulatory quality, enabling policymakers to identify where legislative or rule changes are needed, not just administrative improvements. The refined opportunity cost calculation recognizes heterogeneity in citizens' time valuation, supporting equity considerations (e.g., sludge that costs little for the affluent may be prohibitive for the poor).

Public administrations considering sludge audits face resource constraints and organizational complexity. We propose a tiered implementation strategy.

For organizations with limited resources or seeking initial proof of concept, select high-volume processes that focus on procedures affecting many citizens, where even small reductions in friction yield large aggregate benefits. Conduct process mapping, implementing Steps 1-2 of the model. Apply the uniform opportunity cost formula (Equation 2) using the regional average wage. While this lacks sophistication, it provides order-of-magnitude estimates sufficient for prioritization. Look for steps that consume significant time but serve unclear purposes–these are prime candidates for elimination or digitization. For organizations committed to systematic sludge reduction, measure all five transaction cost categories. Use citizen surveys for psychological costs (validated stress scales), document analysis for red-tape costs, and time-motion studies for implementation costs. Calculate opportunity costs separately for key citizen segments (employed/unemployed, urban/rural, digital-literate/non-literate). Compare findings to similar processes in other jurisdictions. Test elimination of suspected sludge in controlled settings. Track error rates and compliance to ensure efficiency is maintained (apply Equation 6).

Our model, while more rigorous than existing approaches, faces its own constraints. Comprehensive measurement of all five cost categories requires substantial data collection, which can make initial audits resource-intensive. While we include psychological costs, quantifying stress, anxiety, and confusion remains methodologically challenging. We recommend validated instruments (e.g., Perceived Stress Scales),

but acknowledge the potential for measurement error. Determining "efficiency loss" from eliminating steps requires counterfactual reasoning (what would have happened without this step?), which may be speculative without controlled experiments. Threshold values (e.g., what criticality factor to use) require calibration to local contexts, though the framework itself remains generalizable. While we incorporate tacit knowledge systematically, not all frontline insights may be articulable or recognized by workers themselves.

The proposed approach's limitations align with broader concerns about behaviorally informed policy. As Reijula and colleagues (Reijula et al., 2018) observe, interventions targeting individual decisions may not reliably improve collective outcomes unless social interactions and institutional contexts are taken into account.

Despite these limitations, the proposed framework offers a structured and operational approach to identifying and prioritizing sludge within public administration. By decomposing administrative processes into transaction-cost components, the model enables comparative assessment across procedures and institutional contexts. While the evaluation of psychological and opportunity costs necessarily involves judgment, the framework makes these trade-offs explicit, thereby opening them to scrutiny and refinement. As such, the model is intended as a diagnostic and decision-support tool rather than a precise measurement instrument, and can be adapted to different administrative environments and policy objectives.

Comparative institutional analysis could identify which governance structures minimize sludge generation. Do decentralized systems produce more or less friction? Do sunset clauses on regulations reduce red-tape costs? Do citizen participation mechanisms in process design lower psychological costs? As Muramatsu and Barbieri (2017) argue, the prospects of behaviorally informed interventions depend critically on institutional context and the knowledge constraints facing policymakers.

Future research should examine which institutional arrangements facilitate both sludge detection and sustainable reduction while accounting for the limits of top-down optimization (Muramatsu and Barbieri, 2017).

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