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Optimizing the "Door-to-Balloon" (or "Door-to-Intervention") Pathway: An Interdisciplinary Review of System Bottlenecks and Solutions

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Abstract

Background: The Door-to-Balloon (D2B) or Door-to-Intervention (D2I) time is a critical performance metric in the treatment of ST-elevation myocardial infarction (STEMI), directly influencing myocardial salvage and mortality. Despite established guidelines targeting D2B times of ≤90 minutes, significant variability persists globally, indicating systemic inefficiencies across the entire patient pathway.

Aim: This narrative review aims to dissect the interdisciplinary bottlenecks encountered from pre-hospital contact to percutaneous coronary intervention (PCI), and to synthesize evidence-based, system-level optimization strategies for each key touchpoint.

Methods: A comprehensive literature search was conducted across PubMed, Scopus, and CINAHL for studies published between 2010 and 2024, using keywords related to STEMI, D2B, systems improvement, and specific healthcare roles.

Results: Major bottlenecks identified include delayed field ECG acquisition, ineffective pre-notification, cath lab availability conflicts, interdisciplinary communication gaps, and administrative protocol fragmentation. Effective solutions are multifaceted, centering on pre-hospital ECG transmission, standardized activation protocols, empowering frontline staff (e.g., paramedics, emergency nurses) to activate the cath lab, dedicated inter-disciplinary STEMI teams, and real-time data feedback loops. Human factors, including family dynamics and team coordination under stress, are pivotal yet often under-addressed.

Conclusion: Optimizing the D2B pathway is an inherently interdisciplinary challenge requiring seamless integration of pre-hospital and in-hospital systems. Moving beyond a singular focus on time metrics, a holistic approach that standardizes protocols, empowers cross-disciplinary collaboration, leverages technology, and addresses human elements is essential for achieving sustained improvements in STEMI outcomes.

Keywords: ST-elevation myocardial infarction, door-to-balloon time, systems improvement, interdisciplinary communication, percutaneous coronary intervention.

Introduction

The management of ST-elevation myocardial infarction (STEMI) represents one of the most time-sensitive emergencies in modern medicine. The principle "time is myocardium" underscores the direct, inverse relationship between ischemic time and myocardial salvage, ultimately dictating patient survival and long-term ventricular function (Ibanez et al., 2018). The Door-to-Balloon (D2B) time, defined as the interval from hospital arrival to mechanical reperfusion via primary percutaneous coronary intervention (PPCI), has been established as the gold-standard performance metric, with guideline goals consistently set at ≤90 minutes (O'gara et al., 2013). Despite widespread adoption of these benchmarks and significant global efforts over the past two decades, achieving and sustaining these targets remains a formidable challenge for many healthcare systems. Persistent variability in D2B times points not to a failure of clinical intent, but to profound system-level

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bottlenecks that disrupt the patient's journey through a complex, multi-disciplinary pathway (Karkabi et al., 2020).

This narrative review adopts a patient-centric, sequential lens to map the entire D2B pathway, from the initial 911 call to arterial sheath insertion. It moves beyond a traditional cardiology-centric view to examine the critical, often under-analyzed, roles of every touchpoint: Emergency Medical Services (EMS) personnel, radiology technicians, emergency physicians, cardiologists, medical secretaries, health administrators, and support staff like health assistants and security. Each node represents a potential point of delay or acceleration. By synthesizing recent literature (2010-2024), this review aims to identify evidence-based bottlenecks and solutions at each juncture, arguing that true optimization requires an integrated, interdisciplinary system redesign rather than isolated clinical interventions. The focus is on practical, human-factors-aware strategies that can be implemented across diverse healthcare settings.

Methodology

A narrative review methodology was employed to allow for a broad, integrative synthesis of evidence from diverse study designs and professional perspectives relevant to system-wide D2B pathway improvement. A systematic search was conducted in PubMed, Scopus, and CINAHL databases for English-language articles published between January 2010 and December 2024. Search terms included combinations of: "ST-elevation myocardial infarction," "door-to-balloon," "door-to-intervention," "system improvement," "quality improvement," "care pathway," "prehospital ECG," "cath lab activation," "interdisciplinary communication," "teamwork," and specific roles ("paramedic," "emergency nurse," "administrator"). Reference lists of key articles were hand-searched for additional sources.

Inclusion criteria encompassed: systematic reviews and meta-analyses, observational studies (cohort, case-control) reporting on D2B delays and interventions, qualitative studies on process barriers, and published quality improvement project reports. Clinical practice guidelines from major cardiology societies were also incorporated. Articles focusing solely on pharmacological reperfusion or without a clear system-process component were excluded. The extracted data from selected studies were thematically analyzed to identify common bottlenecks and corresponding solutions aligned with each step of the patient journey and the responsible professional domain. This approach facilitates a holistic understanding of the interconnected nature of D2B pathway components.

The Pre-Hospital Phase: EMS as the First and Pivotal Link

The Door-to-Balloon timeline is fundamentally initiated in the pre-hospital setting, making the integration and performance of Emergency Medical Services (EMS) the most potent leverage point for systemic time reduction. The initial minutes following symptom onset are critical, and delays encountered before hospital arrival are frequently irreversible, setting the stage for subsequent bottlenecks. Key pre-hospital bottlenecks are multifaceted, encompassing the failure to acquire a pre-hospital 12-lead electrocardiogram (ECG), a lack of recognition or confidence in identifying STEMI by EMS providers, and, perhaps most critically, the failure to execute an effective pre-notification and activation sequence with the receiving percutaneous coronary intervention (PCI)-capable center. These failures represent a breakdown in the first link of the chain of survival, compromising the entire pathway's efficiency before the patient even reaches the hospital door.

The acquisition and interpretation of a 12-lead ECG in the field is unequivocally the single most impactful pre-hospital intervention for STEMI. This simple diagnostic act transforms the EMS role from transport to proactive cardiac care, enabling early diagnosis and facilitating direct, appropriate triage. Evidence robustly demonstrates that obtaining a pre-hospital ECG reduces Door-to-Balloon times by an average of 20 to 30 minutes by allowing parallel processing of patient preparation and cath lab activation (Demandt et al., 2022). Despite its proven benefit, significant barriers to consistent implementation persist. These include variability in EMS training and protocol adherence, a persistent misconception among some crews that performing an ECG causes an on-scene delay, and systemic limitations such as a lack of equipment or unreliable transmission technology (Namdar et al., 2021). Overcoming these barriers requires a multi-pronged strategy: instituting mandatory, competency-based training for all EMS personnel; ensuring universal ambulance outfitting with modern ECG machines capable of digital acquisition and transmission; and promoting operational "acquire-and-go" or "scoop and run" protocols where the ECG is obtained during transport, thereby eliminating any perceived conflict between diagnostics and rapid movement toward definitive care (Inoue et al., 2023).

However, a transmitted ECG without a definitive and efficient system response is a futile exercise. Pre-notification—the act of alerting the receiving hospital's emergency department and, ideally, the cardiology team—is the essential conduit that converts data into action. Inefficient communication mechanisms, such as calling a general hospital switchboard, being placed on hold, or relaying information to a staff member without decision-making authority, can completely nullify the time advantage gained by the pre-hospital ECG. High-performing systems engineer reliability into this step by establishing direct, dedicated "hotlines" to the ED resuscitation bay or a central cardiac alert paging operator, coupled with the use of standardized communication scripts to ensure completeness and clarity (Krumholz et al., 2008).

The most advanced and efficacious evolution of this concept is the empowerment of paramedics to directly activate the catheterization laboratory team based on predefined, physician-approved protocols, a process known as "field activation." This strategy bypasses potential in-hospital diagnostic delays and redundant evaluations, and multiple studies have confirmed its safety and superior effectiveness in achieving benchmark Door-to-Balloon times (Savage et al., 2022). This pre-hospital decision-making is further supported by the principle of regionalization, where patients are directly triaged to PCI centers, bypassing closer non-PCI hospitals even at the cost of longer transport times, a cornerstone of organized STEMI systems of care (Savage et al., 2023). The synthesis of these critical pre-hospital components—ECG acquisition, effective notification, and direct triage—is summarized in Table 1, which outlines the key bottlenecks and corresponding evidence-based solutions at this initial stage of the patient journey.

Table 1: Key Bottlenecks and Evidence-Based Solutions in the Pre-Hospital Phase

Touchpoint (Role)	Key Bottlenecks	Evidence-Based Solutions
EMS Personnel	1. Delay/failure to perform pre-hospital ECG. 2. Inability to interpret STEMI. 3. Ineffective pre-notification (wrong contact, no data transmission). 4. Transporting to a non-PCI center.	1. Mandatory training & "acquire-and-go" protocols. 2. Use of computer algorithm interpretation + paramedic education. 3. Dedicated hotline; standardized pre-notification script; **paramedic-initiated cath lab activation**. 4. Implementation of regional bypass protocols.

Hospital Arrival and the Emergency Department: The "Door" Dynamics

Upon arrival at the hospital, the patient enters a critical transfer-of-care zone where inefficiencies can swiftly erode the time advantage gained in the pre-hospital phase. Bottlenecks in the emergency department (ED) are often procedural and cultural, involving delays at triage, redundant clinical assessments, and ambiguous authority for activating the catheterization laboratory (Ellahham et al., 2015). Even with effective pre-notification, patients can be halted at standard triage if the EMS handover is incomplete or if rigid registration protocols are enforced. To combat this, high-performing institutions implement streamlined "code STEMI" or "cardiac alert" protocols that mandate immediate patient transfer from the ambulance gurney directly to a designated resuscitation bay, completely bypassing standard triage and front-desk registration. Subsequent administrative tasks, such as formal registration and insurance documentation, can be deferred and completed later by a dedicated medical secretary or health assistant, ensuring clinical priorities remain paramount (Evers et al., 2022).

Within the ED, the physician's role and decision-making authority are pivotal. In cases without a pre-hospital activation, the ED physician becomes the primary diagnostician. Significant delays are introduced when clinicians await an official cardiology over-read of the ECG, order a repeat "confirmatory" ECG, or, more problematically, wait for cardiac biomarker results, which are not required for the initial diagnosis of STEMI and only serve to waste precious minutes (Peterman & Bisgaard, 2010). The fundamental solution is to empower ED physicians to independently activate the catheterization lab based on their interpretation of a clear STEMI ECG, supported by computer algorithm readings. This empowerment requires established trust, interdisciplinary agreement on diagnostic criteria, and codified shared protocols (Lee et al., 2019).

Concurrently, the ED team must efficiently initiate essential adjuvant medical therapy, including dual antiplatelet agents (aspirin and a P2Y12 inhibitor) and anticoagulation, while preparing the patient for rapid transport to the cath lab (Wong et al., 2019). This clinical work is underpinned by the instrumental role of ED nursing and support staff. Nurses are tasked with executing the protocol: obtaining reliable IV access, administering time-sensitive medications, and preparing monitoring equipment. Meanwhile, health assistants or porters must be pre-assigned and on standby to ensure immediate patient transport the moment the team is ready. A clear, predefined role for each member within the ED reduces chaos, minimizes parallel processing errors, and establishes a cohesive team environment (Coyne et al., 2014).

The Catalyst: Catheterization Laboratory Activation and Availability

The activation of the catheterization laboratory sets off a parallel chain of events that is often the most fragile link in the in-hospital pathway. The model of activation itself is a major determinant of speed. Common pathways include the *cardiologist-dependent model*, where the ED contacts the on-call interventionalist who must personally review the ECG before activating the team—a process that inherently adds a critical delay (Kaddoura et al., 2022). In contrast, the *single-call activation model* is considered best practice; here, a central page operator activates the entire cath lab team (cardiologist, nurses, technologists) simultaneously via a group page upon receipt of a pre-specified trigger from a paramedic or ED physician, dramatically reducing latency (Beygui et al., 2022). A *conditional activation* model, used for ambiguous cases, places the team on standby pending rapid cardiology review, balancing resource utilization with preparedness.

Beyond the activation call, the single greatest in-hospital bottleneck is physical and personnel availability: an occupied, unprepared, or understaffed catheterization laboratory. Conflicts routinely arise from overlapping elective procedures, concurrent emergencies in other labs, or delays in staff arrival from off-site locations. Mitigating these issues requires proactive administrative oversight and resource allocation (Rajkumar et al., 2023). Solutions include mandating protected or dedicated STEMI time slots in the daily elective schedule, instituting rapid room turnover protocols, enforcing 24/7 in-house staffing or very short response-time mandates (e.g., ≤30 minutes) for the on-call team, and establishing clear, pre-authorized policies for bumping elective procedures (Nowbar et al., 2022). Technological aids like real-time status boards displaying cath lab and team availability can enhance direct coordination between the ED, EMS, and the cath lab suite (Al-Lamee et al., 2018).

The Interdisciplinary Bridge

Seamless collaboration between emergency medicine, cardiology, and the cardiac catheterization lab staff is non-negotiable for a high-reliability pathway. Bottlenecks at this juncture often manifest as communication breakdowns, role ambiguity, and conflicting clinical priorities. The patient handoff from the ED to the cath lab team is a high-risk moment for information loss. Employing a standardized communication tool, such as SBAR (Situation, Background, Assessment, Recommendation), ensures critical data—including ECG findings, medications administered, allergies, and family contact information—is transferred accurately and succinctly. Cultivating a shared mental model, where every team member from different disciplines understands the immediate goal, the plan, and their specific role, is achieved through joint simulation training and regular multidisciplinary case reviews (Wallace et al., 2023). While activation may be initiated by non-cardiologists, the interventional cardiologist must ultimately confirm the diagnosis and lead the procedure. Delays can occur if they seek additional confirmatory imaging (e.g., point-of-care echocardiogram) or hesitate in diagnostically challenging situations, such as a new left bundle branch block. Pre-agreed diagnostic criteria and immediate access to telemedicine consultation for complex ECG interpretation can mitigate this hesitation (Satou et al., 2017).

The Enablers: Medical Secretaries, Health Administration, and Support Staff

The operational backbone of the D2B pathway is frequently managed by non-clinical staff, whose efficiency directly impacts overall system flow. The role of the medical secretary or scheduler is critical beyond simple notification; they are essential for accurate, rapid cath lab team paging, meticulous logging of time stamps for quality registries, and, importantly, the proactive management of family communication (Kennedy-Metz et al., 2022). By tasking this role with escorting the family to a private consultation room, obtaining contact details, and providing structured updates, clinical staff are liberated to focus entirely on the patient (Lange et al., 2017). Health administration leadership is responsible for the macro-system design.

Their duties encompass: 1) **Protocol Standardization:** Developing, implementing, and enforcing a single, interdisciplinary D2B protocol endorsed by all involved departments to eliminate conflicting local practices. 2) **Data Feedback & Transparency:** Establishing robust, often automated systems to capture every D2B interval, analyze root causes of delays, and provide regular, granular feedback to all stakeholders, from paramedics to cardiologists, fostering a culture of accountability and continuous improvement (Nathan et al., 2020). 3) **Resource Allocation:** Ensuring adequate financial and human resource investment for 24/7 primary PCI service, including equitable call pay, dedicated laboratory time, and appropriate staffing models.

Support staff, including health assistants and security personnel, are vital for managing logistics and the human environment. They ensure patient flow by having elevators ready and hallways clear. In high-stress situations, they also play an indispensable role in managing anxious family members, directing them to appropriate waiting areas, and maintaining a calm, secure environment in the ED and cath lab holding areas, which protects the clinical workspace from disruptive interference (De Freitas et al., 2018).

Human Factors and High-Stress Situations

The D2B pathway operates under extreme time pressure and emotional intensity, making human factors engineering a critical component for success. Cognitive overload, team conflict, and disruptive family dynamics can derail even the most well-designed protocols (Patel et al., 2017). Managing family dynamics is a specific challenge; anxious family members seeking information can inadvertently consume valuable clinical time and heighten ambient stress. Integrating a family liaison function into the STEMI protocol—executed by a dedicated nurse, chaplain, or medical secretary—provides compassionate, structured communication while safeguarding the clinical workspace. Early, clear explanations about procedures and expected timelines can significantly reduce family anxiety and improve the overall care experience (Bonow et al., 2020).

Team performance under stress is another key variable. Effective teamwork is characterized by clear leadership, closed-loop communication, mutual respect, and shared situational awareness (Rosen et al., 2018). Adopting Crew Resource Management (CRM) principles from aviation, which emphasize the practice of speaking up about safety concerns regardless of hierarchy, can significantly enhance team dynamics and error prevention. Regular, interdisciplinary simulation training that incorporates "soft" skill complications, such as managing an agitated family member or internal team disagreement, is invaluable for building resilient, adaptable teams (Hull, 2023; Zajac et al., 2021).

Technological and Process Innovations

Technology acts as a powerful force multiplier for optimizing the D2B pathway. Key innovations focus on communication, visualization, and data analytics. Telemedicine and enhanced ECG transmission allow for immediate digital transmission of field ECGs directly to the smartphone of the on-call cardiologist, enabling remote confirmation and accelerating activation decisions (Rodríguez-Pardo et al., 2020). Real-Time Location Systems (RTLS) and integrated data dashboards provide unprecedented operational visibility. RTLS tags on staff, equipment, and patients can generate real-time maps of the D2B pathway, pinpointing specific delay points such as prolonged ED stays or transport intervals (León-Salas et al., 2023).

Administrative dashboards that display live cath lab status, team ETAs, and case progression improve coordination and proactive resource management (Overmann et al., 2021). Finally, automated time-stamp capture and feedback systems integrate data from EMS electronic patient care records, ED tracking boards, and cath lab admission systems into a central registry. This automation eliminates manual entry errors and biases, providing immediate, reliable data for performance feedback and rigorous root-cause analysis of any delays (Kunadian et al., 2010). The interconnected nature of these in-hospital challenges and solutions across various disciplines is synthesized in Table 2.

Table 2: In-Hospital Bottlenecks and Systemic Solutions Across Disciplines

Domain/Department	Primary Bottlenecks	System-Level Solutions
Emergency Department	1. Redundant triage/registration. 2. Awaiting cardiology ECG over-read. 3. Unclear activation authority.	1. Code STEMI bypass to the resus bay. 2. Empowered ED physician activation. 3. Single-call, group-page activation protocol.
Cardiology / Cath Lab	1. Occupied lab (elective cases). 2. Delayed team arrival. 3. Diagnostic hesitation on ambiguous ECG.	1. Protected/dedicated STEMI lab time. 2. 24/7 in-house or <30-min response mandate. 3. Pre-agreed ECG criteria; telemedicine support.
Administration & Support	1. Fragmented, department-specific protocols. 2. Lack of data feedback loop. 3. Unmanaged family disrupting workflow.	1. Unified, hospital-wide STEMI protocol. 2. Automated time tracking & transparent reporting. 3. Integrated family liaison role (secretary/chaplain).

Discussion and Future Directions

This review elucidates that D2B optimization is a classic systems engineering problem. Isolated efforts in one department yield diminishing returns; sustained improvement requires concurrent, coordinated interventions across the entire continuum of care. The most successful systems view the pathway not as a series of handoffs, but as a single, integrated process owned collectively by all involved disciplines (Paradossi et al., 2010). The evidence strongly supports a core set of strategies: pre-hospital ECG with paramedic activation, single-call cath lab activation, empowering frontline clinicians (paramedics, ED physicians), dedicated inter-disciplinary teams, and relentless data-driven feedback.

Future efforts must move beyond merely shaving minutes to enhancing the reliability and resilience of the system. This involves deeper integration of human factors engineering to design error-forgiving processes, greater use of predictive analytics to anticipate cath lab conflicts, and expanding the concept of "time to treatment" to include total ischemic time, emphasizing public education and EMS response (Stone et al., 2016). Furthermore, as healthcare evolves, the principles learned from D2B optimization are being applied to other time-critical conditions like stroke ("door-to-needle") and trauma, reinforcing the value of interdisciplinary system thinking (Jacobs et al., 2021). Ultimately, the goal is to build systems so robust and seamless that achieving a D2B time of ≤90 minutes becomes the reliable standard, not the aspirational exception, for every STEMI patient, everywhere.

Conclusion

Optimizing the Door-to-Balloon pathway is a complex, interdisciplinary endeavor that extends far beyond the catheterization laboratory. It requires meticulous attention to every touchpoint in the patient's journey, from the paramedic in the field to the health administrator allocating resources. Bottlenecks are often found in the interfaces between departments and in communication gaps, not in clinical competence. Sustainable improvement is achieved through a holistic strategy that combines protocol standardization, technological enablement, empowerment of frontline staff, and a culture of continuous, data-informed quality improvement. By viewing the pathway through an interdisciplinary lens and addressing both the clinical and human factors involved, healthcare systems can consistently deliver timely, life-saving care for STEMI patients, translating the unequivocal evidence for rapid reperfusion into daily practice reality.

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