A Clinical Decision Support System to Improve PN Core Measure Reporting

Eric Abbott, Nancy Casazza & Kevin Scharnhorst

The authors describe a Clinical Decisions Support System (CDSS) application called “To the Core” that solves the problem of collecting, aggregating, and reporting of core measures from disparate data locations. The proposed solution is demonstrated using the pneumonia (PN) core measure set. Considerations include the environment, stakeholders, workflow improvements, the system design, architecture, constraints, the user interface, and knowledge engineering/decision logic.
# Table of Contents

**INTRODUCTION** .................................................................................................................................................. 3  
**BACKGROUND INFORMATION** .................................................................................................................. 3  
**STAKEHOLDERS, GOALS AND OBJECTIVES** ........................................................................................... 4  
**INFORMATION SYSTEM INVENTORY** ........................................................................................................... 7  
**INTERVENTION SELECTION AND WORKFLOW OPPORTUNITIES** .............................................................. 8  
**CHANGE MANAGEMENT PLAN** .................................................................................................................... 11  

**SYSTEM DESIGN** .......................................................................................................................................... 15  
**MODEL** ..................................................................................................................................................... 15  
**DESIGN DOCUMENT AND ARCHITECTURE** .............................................................................................. 16  
**INTERVENTION (CONTENT) SPECIFICATION** ............................................................................................. 18  
**USER INTERFACE** ..................................................................................................................................... 20  
**KNOWLEDGE ENGINEERING** ..................................................................................................................... 22  

**EVALUATION** .................................................................................................................................................. 22  

**DISCUSSION** .................................................................................................................................................. 24  

**WORKS CITED** ............................................................................................................................................. 26  

**APPENDICES** ................................................................................................................................................ 29  
  1 – PN-3A DECISION TREE LOGIC ...................................................................................................................... 29  
  2 – PN-3B DECISION TREE LOGIC ...................................................................................................................... 32  
  3 – PN-6A DECISION TREE LOGIC ...................................................................................................................... 36  
  4 – PN-6B DECISION TREE LOGIC ...................................................................................................................... 41
Introduction

Background Information

In the last decade, the application of Healthcare IT (HIT) systems to improve the quality of care, patient outcomes, and access to care has grown immensely. HIT provides enumerable benefits, most notably evidenced via the application of Electronic Medical Records (EMRs) to promote continuity of care and increased patient safety through effective documentation of clinical encounters. More recently, the performance of healthcare delivery systems has come under intense scrutiny given escalating costs of care and evidence based medical practices designed to improve the effectiveness of care. Driven by legislative, professional, and industry associations, the healthcare delivery system is now realizing Computerized Physician Order Entry (CPOE) and Clinical Decision Support Systems (CDSS) that strengthen the value proposition behind collective efforts underpinning Meaningful Use (MU). Specifically, the HITECH Act (2009 ARRA) provides funding mechanisms and strengthened social motivations and social abilities designed to spur adoption of CDSS. In this framework, accreditation and watchdog agencies such as the Agency for Healthcare Research and Quality (AHRQ) and The Joint Commission (TJC) are driving clinical guidelines and performance measures to improve care, and CDSS provides such a vehicle.

Core measures were originally introduced to raise the quality of care and to improve clinical outcomes. They have since become metrics of minimum standards of care and are thus indicative of a healthcare organizations (HCO’s) commitment to operational excellence. However, abstracting and compliance reporting of core measures remains difficult for HCOs: data is often warehoused in separate locations, semantic interoperability of Information System (IS) remains a challenge, and schemas using HIT-based process and practice standards are inconsistently implemented. There are several core measures reflecting prevalent social markers of disease. As such, the measures are used to evaluate the efficacy of the prevention, management, and treatment of diseases to which they are associated.

The monitoring of core measures is a requirement for healthcare organizations (HCOs). In 1999, TJC requested input from multiple stakeholders regarding “potential focus areas for core measures for hospitals” (The Joint Commission, 2010). In May 2001, TJC presented four initial core measurement areas for hospitals, which included PN, Heart Failure (HF), Acute Myocardial Infarction (AMI), and Surgical Care Improvement Project (SCIP) (The Joint Commission, 2010). During this same time, TJC worked with the Centers for Medicare & Medicaid Services (CMS) to align common measures (The Joint Commission, 2010). Today, there are 14 core measure sets that hospitals may utilize. However, hospitals are only required to report a minimum of 4 core measure sets (The Joint Commission, 2011, November 18). Each core measure has a specifications manual that provides rules and instructions regarding each individual performance measure included within the overarching core measure set, and this manual is updated every six months.

The authors chose the PN core measure to demonstrate the value proposition of applying a CDSS for core measure reporting. PN is an infection of the lung that affects millions of people in the U.S. annually (NIH, 2012). PN can quickly lead to acute respiratory failure, causing death. Therefore, rapid and evidence based treatment is imperative to reduce morbidity and mortality from this disease (NIH, 2012). The PN set consist of the two performance measures listed in the table below. Previous measures PN-1, PN-2, PN-4, PN-5, and PN-7 were retired. All current measures are
endorsed by NQF per TJC, and are designed to be used together to promote outcome quality improvements in patients with pneumonia (The Joint Commission, 2011). Table 1 shows all active measure set(s) under the PN core measure.

<table>
<thead>
<tr>
<th>PN Performance Measure Set</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PN-3a</td>
<td>Blood cultures performed within 24 hours prior to or 24 hours after hospital arrival for patients transferred or admitted to the ICU within 24 hours of hospital arrival</td>
</tr>
<tr>
<td>PN-3b</td>
<td>Blood cultures performed in the ED prior to initial antibiotic received in hospital</td>
</tr>
<tr>
<td>PN-6a/b</td>
<td>Initial antibiotic selection for community acquired pneumonia in ICU or non-ICU</td>
</tr>
</tbody>
</table>

Table 1

The current difficulty with abstracting core measure data is the required information/data can be located most anywhere in the EMR, and it may be in text form, making it difficult to locate and thus abstract the data. Exacerbating this problem is that some hospitals perform a sampling of their core measure patients, while other hospitals perform a 100% review (The Joint Commission, 2011). By utilizing “a statistically valid sample” “a hospital can measure its performance in an effective and efficient manner” (The Joint Commission, 2011), but by utilizing a sampling method only a limited number of patients are being assessed. For example, if a hospital samples 20 patients per month, they may miss an opportunity to improve quality issues related to the measure. Furthermore, there are workflow inefficiencies: many hospital EMRs do not lend themselves to efficient data abstraction, and the time expended to hand-abstract this data is impractical (Metzger & Schmidt, 2009). From an operating cost standpoint, hospitals may employ external agencies to perform this task, which represents a large expense, negatively impacting cash flows. While there are applications and tools designed to improve the process, they still require manual intervention in the form of an abstractor to review the EMR and manually locate the data.

To the Core solves this problem by providing physicians with clinical decision options that achieve an integrated collection, aggregation, and reporting of core measures having the following benefits:

- Increases patient safety, outcomes, and quality of care;
- Positively enhances operating cash flows by reducing HCO costs of operation;
- Increases clinical efficacies and measurements through dashboard reporting of quality of care metrics via compliance to core measures;
- Promotes workflow improvements specifically by eliminating manual interventions, and;
- Enhances HCO operations management and competitiveness through better alignment of people, process, and technology to strategic initiatives such as Pay for Performance (P4P) and Accountable Care.

**Stakeholders, Goals and Objectives**

There are multiple external and internal stakeholders who share the benefits of this CDSS. External stakeholders include the community, shareholders (For-Profit), benefactors (Not-For-Profit), Payors (i.e., CMS), and Payees (i.e., the patient). Payors are seeking high quality, low cost service, and patients desire efficacious treatment options with optimal outcomes. Internal stakeholders include all those who are involved in the provision and delivery of care, namely, the HCO’s governance committee, the executive board (i.e., ‘C’ suite), and clinical and operational groups. The latter are
particularly significant since they directly benefit from the CDSS, and specific functional areas include physicians, nurses, clinicians, pharmacy, labs, and ancillary.

The primary goal of the CDSS is to improve the data collection, aggregation and reporting of core measures to reduce unnecessary health care costs (Clancy, 2009) and ultimately improve patient outcomes. Secondary goals are to automate the process and to ensure that the application has many desirable attributes of quality. These include but are not limited to the following (Berner E. S., 2007):

- Ease of adoption;
- Favorable technical attributes (i.e., scalable, extensible, highly-available, standards-based);
- Integration capabilities with an EMR;
- Minimal maintenance;
- Astute knowledge database, rules engine, and interfaces/communication modalities.

Given MU and other similar HIT technology acquisition activities (i.e., CPOE), integration of the CDSS to an EMR is prima facie. Therefore, from a structural standpoint, the CDSS lends itself well to the primary objective of supporting quality measurements and improvements to care coordination so that clinicians and patients have information necessary to optimize care (Clancy, 2009). Secondary objectives include but are not limited to the following:

- Reduce “the risk of harm from health care services by using evidence-based research and technology to promote the delivery of the best possible care” (Clancy, 2009);
- Improve “health care outcomes by encouraging providers” “to use evidence-based information to make informed treatment decisions” (Clancy, 2009);
- Reduce operating costs by 80% over current practices associated with core measure reporting;
- Achieve a 20% uplift to HCO revenues through adoption and utilization of the CDSS.

The latter two are particularly relevant. As mentioned, HCOs are the primary stakeholders in this process. With decreases in reimbursements and greater scrutiny in terms of clinical care and outcomes (to wit: ACOs, P4P, and Physician Quality Reporting Initiatives or PQRI), HCOs have to ensure they evaluate all avenues for revenue loss/gain and the inability to accurately monitor, act on, and report quality measures can have a detrimental effect, not only with CMS (i.e., Medicare and Medicaid) but also with private insurance companies. In 2013, the Hospital Value Based Purchasing Program (VBP) will be enacted (Administration Implements New Health Reform Provision to Improve Care Quality, Lower Costs, 2011). Beginning in October 2012 with inpatient discharges, “Medicare will reward hospitals that provide high quality care for their patients” (Administration Implements New Health Reform Provision to Improve Care Quality, Lower Costs, 2011), and many of the measurements used to assess these reimbursements will be extracted from the core measures. Additionally, “in 2013 hospitals will receive a payment reduction” (Administration Implements New Health Reform Provision to Improve Care Quality, Lower Costs, 2011) if they have excessive 30 day readmission rates for Heart Failure, Pneumonia and Acute Myocardial Infarctions: in other words, all the core measure sets (Administration Implements New Health Reform Provision to Improve Care Quality, Lower Costs, 2011). Accordingly, HCO goals
and objectives need to be keenly aligned with the designated quality measures. It will be the HCOs responsibility to ensure all necessary processes are in place to provide patients with quality care. Physicians will be required to more closely align their goals with those of the HCO due to the upcoming VBP requirements. Thus, physicians who may not have previously worked closely with HCOs (i.e., private practices) will be evaluated on patient care if their patient is admitted to a hospital. In other words, the care setting is no longer a differentiator for the performance of care. Moreover, with electronic systems being implemented to ensure that specific guidelines are met, physicians are going to have to adjust to new workflow patterns. Core measure reporting thus has an immediate and determinate effect on the workflow pattern of the physician in this new reality.

Nurses play a pivotal role towards ensuring that quality measures are met. Indeed, they are responsible for some of the measures themselves and have additional abilities to remind physicians if some aspect of care has been missed. Implementing a CDSS that reduces charting redundancy positively improves nursing efficiencies from a workflow standpoint. To the Core not only promotes workflow improvements, but it mitigates errors of omission and errors of commission by eliminating complexity and simplifying nursing workflows (Osheroff, Pifer, Teich, Sittig, & Jenders, 2005). An ancillary benefit is that CDSS also alleviates nursing workload so that nurses are more productively utilized for life critical activities (Liebovitz, 2010).

Pharmacy Information Systems and Lab Information Systems are key beneficiaries of the CDSS. One of the core objectives of the Pharmacy Department is to improve inpatient antibiotic utilization, an area of frequent concern, particularly given selection and demand for the latter based on presenting diseases such as PN. Additionally, the Pharmacy Department must also address efforts to more effectively dispense antibiotics based on measures to minimize over-utilization, and to demonstrate compliance to operations management of costs arising from unnecessary treatment. Similarly, the Lab Information System is also a key recipient of this application. An objective of the lab is to ensure appropriate utilization of antibiotic removal device (ARD) blood culture tubes and non-ARD blood culture tubes. This is a cost saving and quality measure in that ARD tubes are more costly than non-ARD tubes and should only be utilized in specific situations. The lab will incorporate the monitoring of this metric to help pinpoint educational opportunities.

Additional stakeholders include external abstraction companies and third party quality management vendors. Development of a CDSS managed internally that promotes data outcomes collection efficiencies may be viewed detrimentally to some, and beneficially by others. If the HCO successfully implements the CDSS, then contracts with external vendors that previously provided elements of CDSS functionality will no longer be necessary. However, streamlining of the reporting process and cost reductions (to the HCO) are a few of the objectives behind the CDSS, hence attainment of these objectives is one measure of success. As for Quality Check (i.e., the TJC core measure site) and Hospital Compare (i.e., the Medicare core measure site) both will need to start working with individual HCOs instead of gathering this information from vendors. This will likely increase demand for accelerating the Nationwide Health Information Network (NHIN). The authors caution that such agencies may be resist such change until sufficient CDSS adoption is achieved, justifying such as process change.
Information System Inventory

An integrated CDSS knowledge-based information system architecture must exist in order to achieve the outlined goals for collection, aggregation, and reporting of core measures efficiently. Additionally, the solution will be based on a service oriented architecture (SOA) in order to build in flexibility to extend the intended design to report any number of core measures in the future. That is to say, while the initial solution targets the PN core measure, it is flexible to allow “plug and play” of other core measures for quality reporting.

The benefits of an SOA approach are in the alignment of already-owned information technology (IT) assets in such a way that “business needs are fulfilled through the orchestration of platform-neutral, network-accessible software services that provide core business functions through well-defined interfaces” (Kawamoto, Honey, & Rubin, The HL7-OMG Healthcare Services Specification Project: Motivation, Methodology, and Deliverables for Enabling a Semantically Interoperable Service-oriented Architecture for Healthcare, 2009). The components comprising the CDSS solution are described below.

- **EMR –** An electronic medical records system must exist and be used in practice at the critical junction points for the core measure. For the PN measure, this includes admitting, medical records/HIM/coding, lab, pharmacy, physician note/documentation entry, radiology, medication administration record (MAR), ED, and inpatient. Areas within the medical record that accept free form text must have a means to convert the latter to structured data elements. Alert mechanisms to users for action prompts will be received here. Trigger mechanisms will also exist at this layer and will be used to send data to match rule criteria. Abstractors will identify relevant data elements and map them to the virtualized medical record (vMR).

- **Knowledgebase –** Following SOA principles, a system independently will exist to contain the rules and logical conditions that define the criteria that are being considered for action. A knowledgebase generally “consists of compiled information that is often, but not always, in the form of if-then rules.” (Berner E. S., 2007). For core measures such as PN, performance specifications may be updated, and a knowledge author will translate the rules (for the denominator and numerator) from the specifications manual into a machine interpretable format.

- **Inference Engine –** This is the “reasoning mechanism, which contains formulas for combining the rules or associations in the knowledge base with the actual patient data” (Berner E. S., 2007).

- **Enterprise Service Bus (ESB) –** Used to host reusable SOA-based services or interfaces where composite services can be built to do orchestrations. It contains the data mapping framework needed for basic extraction, transformation and load (ETL). This critical later provides the “glue” to ensure that data exchange communications are supported across disparate (and remote) systems so that one cohesive data stream is achieved. A virtualization layer exists within the ESB framework to tie existing service end points into one area for discoverability. Service directory services exist to share capabilities with inquiring external consumers.

- **Measurement System –** In order to report on measure performance, the TJC requires a system that is composed of the following: a set of process and/or outcome measures of performance; processes for collecting, analyzing and disseminating these measures from multiple organizations; and an automated database. (The Joint Commission, 2011). The TJC sets forth a goal of being able to “generate both internal comparisons of each participating organization’s
performance over time, and external comparisons of performance among participating organizations” (The Joint Commission, 2011).

- **Data warehouse** – Due to the unstructured nature of medical information and varied sources, structured medical terminology will be enforced through the electronic systems that collect it at entry using adopted ontologies. Textual notes will be transformed using ETL processes and then collected and stored in a data warehouse. Analytical tools will be made available to clinicians for reporting and trend analysis. All data residing in the warehouse will be de-identified.

- **Infrastructure** – Obvious networking capabilities must exist to make the whole solution possible. Along with network infrastructure, the necessary servers, workstations, medical devices, remote access need to exist, and where not available, acquired to support the recommended model.

All of the above are feasibly provided in tools that are available through open source means. Where open source is available it will be preferred to achieve cost savings opportunities and to also embrace those that favor standards-based protocols to foster semantic interoperability.

**Intervention Selection and Workflow Opportunities**

Based on hypothetical workflows at an HCO, PN patients may enter the hospital in one of three ways:

- **Directly admitted from a physician’s office**: The patient is scheduled for an outpatient visit and upon evaluation is so ill that the physician admits the patient directly to the floor, directly to an ICU, or sends them to the Emergency Department (ED);

- **Shows up in the ED**: The patient arrives at the ED as a walk-in or in an ambulance from home;

- **Transferred from another ED**: The patient is seen in an external ED or is admitted to an external hospital, and the external hospital realizes the complexity of the situation is more than they can manage.

Five scenarios are applicable to the above, and are illustrated below in figures 1 through 5.

*Scenario 1: Arriving through the ED*
**Scenario 2: Admitted to the ICU from the ED**

**Figure 1**

**Scenario 3: Admitted to the floor from the ED**

**Figure 3**
Scenario 4: Direct admit to the floor (did not utilize the ED—from MD office or another hospital)

![Diagram](image)

Figure 4

Scenario 5: Direct admit to the ICU (did not utilize the ED, from MD office or another hospital)

![Diagram](image)

Figure 5

The CDSS has a general workflow such that once a core measure diagnosis is determined (based on DRGs placed into the EMR system), the EMR automatically notifies the physician, who then accesses the user interface of the CDSS in order to follow specified guidelines and to address pertinent performance indicators. This is accomplished by interacting with the system to place orders that minimally meet the core measure criteria. Upon completing this activity, the physician would evaluate order sets or place additional orders as structured by the CDSS. For example, if the physician needed to order an antibiotic for a PN patient; the ‘Pneumonia Core Measure link’ would provide the following:
• List appropriate antibiotic(s);
• Query the physician if blood cultures were drawn;
• Provide abilities to adjust antibiotics for patient-specific indications (i.e., renal function);
• Inform of any allergies, possible drug-drug interactions, and;
• Provide a patient geo-location (i.e., floor versus ICU).

The CDSS would provide clinical updates to the appropriate data fields in the EMR. This is important for continuity of care, for documenting the patient’s treatment, and for clinical performance analysis. It is noteworthy that the CDSS eliminates workflow redundancy by automatically performing these steps. This ensures that communications and updates between caregivers are timely and efficient. To illustrate the process using another example, suppose a nurse needs to document that a Foley catheter has been discontinued (as is the case with the SCIP core measure). In this situation, the nurse would access the appropriate core measure in the CDSS tool, and enter the pertinent information. Auto-populating is accomplished, including possibly the intake/output section with the date/time the Foley catheter was discontinued.

Once the patient is discharged, the CDSS provides abstraction and submission of the relevant data to the designated receiving entities or clearinghouses (as elected by the HCO). The timeframes that govern this process may be adjusted depending on reporting requirements. For instance, if disease surveillance requires an increase in public reporting of PN (due to an infectious outbreak), the reporting process may be adjusted to meet mandated for specified requirements (i.e., Centers for Disease Control and/or CMS mandates). Otherwise, after a certain time period, say, two weeks after the end of a month, a clinician or informaticist can extract indicated core measure DRGs to obtain the appropriate patient population, and then run a report that provides all the information for each individual patient regarding each respective individual measure. At this point, the HCO has the option to upload the data indirectly via a third party or directly into designated websites (such as Hospital Compare http://hospitalcompare.hhs.gov). In the latter scenario, the advantage is that the process is automated and it eliminates the need for an extra step in the process, which introduces risk (i.e., error) and cost. The disadvantage is that the decision making algorithm for inclusion/exclusion of reporting becomes incorporated into the CDSS application, which requires regulatory and safety approvals of the application by TJC and others prior to use (The Joint Commission, 2011). Thus, initially, it may be more advantageous to employ the indirect upload method until such approvals are achieved. However, in this case, the disadvantage is that the process is not completely automatic, and the hospital incurs additional costs to manage the data abstraction time to a third party database to manage and upload quality database.

**Change Management Plan**

Given the importance ascribed to the success of this CDSS, a project management approach will be used to ensure its successful implementation. The CDSS project will deliver a tightly integrated set of capabilities that interface to a broad spectrum of users and functions. Use of a Program Management Office (PMO) and Project Management foundations will provide consistency in communication, status reporting, and tools for managing implementation of the project.

As with introduction of any new technology, several considerations need to be addressed. These include stakeholder perceptions and expectations, project objectives and goals, risks, benefits, and
contingency plans. Success factors for a CDSS include the following (Osheroff, Pifer, Teich, Sittig, & Jenders, 2005):

- **Executive level support**: Provided by the Board of Directors (BoD) or a designated executive sponsor;
- **Acceptance**: Social motivation to ensure adoption and acceptance of the CDSS. Educational sessions and presentations can greatly facilitate communications of the value proposition and benefits;
- **Excellent communication**: Use of a PMO and other method to ensure that all stakeholders are apprised of the progress and success of the project. The PMO will manage core team members and subject matter experts (SMEs) associated with the project. Use of Project Management Body of Knowledge (PMBOK) process including waterfall process to maximize stakeholder input and comments. A stage-gate process is recommended using house of quality checks, followed by acceptance and training.
- **Key user participation**: Involvement of key users to and champions such as SMEs to provide input, training, and guidance at various stages of implementation;
- **Problem Resolution**: Use of PMO and other core team participants to provide timely feedback and resolution of issues to minimize risk and maximize project success.

Careful consideration and education planning will be put in place due to the significant workflow changes that would occur with this type of application. Considering the three ways patients arrive at a hospital and the five scenarios in which the PN core measure will be applied, the core team will engage the Human Resources department to conduct a workflow assessment of current work patterns. The team will then consider the current patterns in designing the new application. After a gap analysis is completed, an action plan will be implemented to resolve any issues so that the CDSS is minimally disruptive to workflows, promoting its adoption and eliminating impacts to present workflow patterns. The core team will use a stage gate change management process, which is illustrated below (AHRQ, 2012).
The first step consists of assessing readiness for implementation of the CDSS, including identification of the goals and objectives to ensure that the value and rationale is understood. The second step consists of establishing perspectives from a quality and total cost of ownership (TCO) perspective. This may involve conducting surveys to key stakeholders at the hospital. The third step involves structural and social motivation techniques such as creation of an executive sponsor team and hosting of educational seminars and issuance of informational bulletins to create awareness of the need for the CDSS. The fourth step gathers data from the external environment such as regulatory data and a review and examination of similar implementations at leading institutions. This serves to de-risk the project through knowledge transfer and lessons learned based on comparable implementations. The fifth step gathers data from internal stakeholders using focus groups, reviews of workflow processes (current methods, implementation impacts, and blueprint improvements). Participants include nurses from the nursing pulmonary floor, ED physicians, intensivists, hospitalists, pharmacists, and lab resources. Last, appropriate tools (i.e., LEAN methodologies) will be used to implement the CDSS. As part of this stage, a pilot will be conducted to eliminate risk and to capture workflow improvements using pre and post deployment measurements of clinical performance based on time, accuracy, responsiveness, and quality attributes. Following the pilot, and after any necessary changes to the CDSS are made, training and educational sessions will be conducted for all system users. Participation by the pilot users will be encouraged to promote training and also to ease concerns. Upon successful completion, full scale roll-out of the CDSS will be undertaken. During this phase, staff members will be available 24x7x365 for several months to assist with any questions regarding new workflow patterns and other adjustments.
To ensure “house of quality” metrics around CDSS execution and delivery, a waterfall system development life cycle (SDLC) approach will be implemented at each step as illustrated in figure 7 (Shortliffe & Cimino, 2006).

![Figure 7](image)

The project management schedule for implementation is shown in table 2. Project execution is expected to take less than a year.

<table>
<thead>
<tr>
<th>Core Measure CDSS Project Plan</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase I: High-Level System Requirements</strong></td>
<td>J F M A M J J A S O N D</td>
</tr>
<tr>
<td>Stakeholder Analysis</td>
<td>★</td>
</tr>
<tr>
<td>Workflow Analysis</td>
<td>★</td>
</tr>
<tr>
<td>Options Analysis</td>
<td>★</td>
</tr>
<tr>
<td>Business Plan</td>
<td>★</td>
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<tr>
<td><strong>Phase II: Development</strong></td>
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<tr>
<td>Design and Integration</td>
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<tr>
<td><strong>Phase III: Implementation</strong></td>
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<tr>
<td>Education</td>
<td>★</td>
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<tr>
<td>Integration (EMR, Financial)</td>
<td>★ ★</td>
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<td>System Pilot</td>
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<tr>
<td>Benchmarking</td>
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<tr>
<td><strong>Phase IV: Test and Acceptance</strong></td>
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<tr>
<td>Full Roll-Out</td>
<td>★</td>
</tr>
<tr>
<td>Close-Out of Prior Practices</td>
<td>★</td>
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<tr>
<td>Documentation and Training</td>
<td>★</td>
</tr>
<tr>
<td>System Go-Live</td>
<td>★</td>
</tr>
</tbody>
</table>

Table 2
System Design

Model

The model for the To the Core is driven from core measure specifications. To understand the varied interaction points and functional requirements, use case modeling are employed along with unified modeling language (UML) principles to abstract activities, actors (i.e. stakeholders whether human or system), business processes, database schemas, and reusable software components. Use case modeling can be done by either visual or narrative forms. However, both accomplish the same purpose in identifying all the varied roles and interactions within a defined process.

Good design practices mandate the use of open standards to ensure interoperability and reuse of existing technologies to minimize development effort. To the Core CDSS leverages an existing CDSS platform, OpenCDS, for its engine and analytics model. OpenCDS incorporates best practices and standards established by the Healthcare Services Specification Project (HSSP) by leveraging the Service Specification Framework (SSF). Infrastructure standards include Web Services Description Language (WSDL), XML Web services and UML for establishing specifications. Ontologies recognized in the solution include CPT, ICD9, ICD10, SNOMED CT, LOINC, RxNORM, HL7 information models, OpenEHR archetypes and Continuity of Care Record (CCD) model (Kawamoto, Honey, & Rubin. The HL7-OMG Healthcare Services Specification Project: Motivation, Methodology, and Deliverables for Enabling a Semantically Interoperable Service-oriented Architecture for Healthcare, 2009).

The knowledgebase and rules engine is incorporated inside the OpenCDS core platform, permitting simplistic customization for the To the Core CDSS. Core Measure rule criteria can be entered, removed or modified from a standard GUI, accessible via a web interface. Test cases are run in an automated fashion to encompass new rule criteria or to do regression testing against existing standards. Individual rule sets are termed knowledge modules. To operationally illustrate the model’s workflow, a graphical representation is provided in figure 8. A retrieve, locate, and update service (RLUS) represents a hypothetical physician reviewing a patient’s medical information through EMR interaction with the CDSS. Necessary data elements are collected from the physician in order to make a recommendation for care plan based on inference provided from the CDSS based on criteria-matching to a rule.
The same general approach can be extended to the patient care management workflows with the eventual output (Step 8-9 above) changed to send data to a measurement system when the measure has been evaluated. If not, the clinician is prompted further action until it is met. In this way, the model supports the twin objectives of improving HCO reporting and increasing the quality of care.

**Design Document and Architecture**

From the OpenCDS High-Level Architecture, internal components clearly illustrate interaction methods from inputs (i.e., patient data from an EMR) to outputs (i.e., machine-interpretable conclusions) through knowledge modules (Kawamoto, DSS Standard, vMR Standard and OpenCDS Reference Implementation, 2012). In figure 9, “Knowledge Consumer” is the EMR.
Knowledge rules are compiled into deployable packages that can be shared among distributed locations within the HCO or generalized to be shared regionally or nationally (i.e. HIE, NIHN, and so forth over the internet). Knowledge Modules are key components, created using an open-source Drools inference engine that employs domain specific language (DSL). DSL makes it possible to write the rules so that they are articulated how clinicians would describe them, using terms that clinicians use every day (Shields, 2011). Defined within the architecture are trigger mechanisms that...
are pulled when a given circumstance is met. For example, this may occur when a patient medical record is updated with a DRG code related to PN. The associated data accompanying the record is then sent to the DSS to be considered against the core measure.

![Figure 10](image)

(Kawamoto, DSS Standard, vMR Standard and OpenCDS Reference Implementation, 2012)

**Intervention (Content) Specification**

Informational content that drives decisional determinations is sourced from the EMR and from the CDSS knowledge database. The former contributes patient-specific information such as the results of a chest X-ray upon admittance to an ED. In conjunction with data from the EMR, the latter contributes codified clinical knowledge that drives a rules engine to issue triggers for certain actions, such as ordering of a blood culture test. To ensure interoperability, standards based informational payloads will be leveraged across the HCO and will be passed to the CDSS for inference. An example of this process is illustrated in the flow diagram below with PN triggers.

The entire process is driven on suggested workflow decision trees supplied by the performance measure for each core set within the PN core measure. At decisional points within the workflow, the EMR and CDS interact cohesively to evaluate and designate preferred outcomes. Notably, since performance measures center on improving procedures, patient preferences (or utility values) are not taken into account. The goal is attainment of a higher level of compliance for the core performance measure (in this example, PN). The proposed implementation achieves the following usability and design aspects.
Subject Matter Experts (SMEs): knowledge is directly captured through electronic means and centrally stored in the knowledge modules. Direct ownership over logical rules will instill confidence in DSS knowledge source, contributing to increased levels of adoption and acceptance. Knowledge modules can be regressively tested to ensure expected outcomes;

- Knowledge-retention strategy is native to the solution and protects the HCO from loss of CDSS maintenance expertise arising from clinician turnover;
- SME knowledge is reusable and can be shared with both internal/external entities;
- By using DSL, the CDSS will provide intuitive capture of clinical rule input(s). Assertions or determinations will be decipherable by clinically-focused end users.

Referring the above figure 10 & 11, trigger condition will be met based upon collected data elements entered by the clinician(s) on the electronic medical record (EMR) related to PN-3a, PN-3b, PN-6ab. (i.e. patient having ICD-9-CM principal diagnosis (dx) of pneumonia, 18 years or older Length of Stay (LOS) within considered scope). EMR native data format containing the patients list of active problems, medications and lab results will be sent to ESB. The ESB will transform EMRs native format to extensible markup language (XML) representation. Extensible Stylesheet Language (XSLT) will be applied to XML to transform to HL7 Continuity of Care Document (CCD) or HL7 vMR format required by the DSS. These formats are based on normative HL7/ANSI standards. The DSS will accept the request with the HL7 message as its input, make an inference through comparative criteria analysis using the knowledge modules and then return the determination back to the requestor (the ESB) in an HL7 Care Plan or HL7 vMR format. The ESB will parse evaluation results and transform to required format needed by the EMR. The ESB will then return the transformed evaluation results to its requestor (the EMR). The EMR will key off decision results and prompt clinician for additional data needed to meet the performance measure if patient is determined to be a fit for consideration in the denominator or numerator of the measure.
If the measure is satisfied, the episode will be sent again to the ESB. The ESB will accept the measure data for the active episode and do transformations to insert this data into the measure system using standards established by HITSP/CAP 130 (HITSP Communicate Quality Measure Data Capability) which is a content based standard that has been established to aid in creating eMeasure for exchange of quality measure information from an EMR or HIE. (HITSP, 2010).

On pre-determined intervals, measurement data will be published from the measurement service following interface specifications established by the TJC. Content specification for outputs will natively adhere to the HL7 HQMF standard. The HL7 HQMF standard is a newly released standard released in 2010 used to encode quality measures (aka creating eMeasures). The HL7 HQMF standard is part of the HL7 Version 3.0 family of standards, based on a Reference Information Model (RIM) (HITSP, 2010). Where possible and feasible, the TJC can subscribe to updates in the measurement system and achieve a real time feed of reporting data using a publish/subscribe model.

User Interface

To the Core has a two-fold user interface. The primary interface is the EMR in which clinicians collect and build problem lists as they progress through a patient encounter. The CDSS adds intelligent decisional support capabilities via a knowledge base that includes rule criteria. An interface engine otherwise known as an Enterprise Service Bus (ESB) resides between the CDSS and the EMR, and is responsible for mediation, transformation, and routing of data. When EMR problem list criteria align to CDSS knowledge database modules, the CDSS rules engine interrogates the data using rule criteria. Recommendations are then made to the user in real time that proactively guides core measure reporting. For example, figures 12 and 13 show two alerts below show a PN-

A second interface is one specifically purposed for clinicians that create and maintain business rules. “Drools” is the name of the inference engine within the CDSS. As core measure rules are released by the TJC, they are interpreted and captured in electronic form by knowledge author entry. The latter is generally a nurse or informaticist with a strong domain background specific to
the measure at hand. The rules are built using domain specific language (DSL) that contain if/then branching logic that specify what criteria have to be met in order to satisfy all conditions. Rules can be isolated into packages that are data specific. An example is included in the image above for PN-3b. Once the knowledge is captured and retained in a rule package it is a software asset. Packages are deployable within an organization and can even be shared or exchanged with external entities, fostering external collaboration.

As knowledge authors build rules, flexibility exists to design to any level of granularity. The PN-3b core measure lists two sets of criteria that must be met in order to satisfy the whole measure (i.e., the Denominator and Numerator). As in the user interface example in figure 14, segmentation can be done to encapsulate the rule logic for the Denominator and the Numerator separately.

The “Post_CreateOutput” requires that both “DenomCriteriaMet” and “NumCriteriaMet” conditions are both satisfied in order to generate output for the whole quality measure as shown below. (see figure 15)

The user interface for authoring rules is very intuitive and requires minimal training in order to become productive. Figure 16 is a sample of the PN-3b Denominator criteria. Note that all conditions have to be met in order to satisfy the Denominator criterion.
Knowledge Engineering

The Specifications Manual for National Hospital Inpatient Quality Measure provides information regarding performance measures and their required data within a six month time frame. Updates and release notes are available from TJC and others more than six months prior to the required utilization and implementation, enabling HCOs to update their abstraction and documentation processes. Since changes and/or updates are required on January 1 and July 1 of every year, program updates for To the Core would be conducted on March 1 and September 1 (or the closest work day) of every year. This gives programmers time to apply the updates and then test the system for issues. To preserve knowledge, ‘versioning’ links “knowledge to interventions even in retrospect years after the intervention” (Osheroff, Pifer, Teich, Sittig, & Jenders, 2005).

Evaluation

Evaluation of the CDSS should closely follow best practice medical acquisition processes that are both objective and subjective (Shortliffe & Cimino, 2006). Fundamentally, comparative effectiveness of the CDSS with respect to attainment of project goals and objectives is paramount, namely: improved clinical outcomes; 100% PN core measure reporting; reduced HCO operating costs, and; minimal workflow impacts. A pivotal methodology is to assess operational effectiveness prior to and after implementation. Several approaches are possible that both quantitative (objectivist) and qualitative (subjectivist) methods. An example of the former is an RCT, and that of the latter are behavioral studies conducted by expert panelists. To this last point, usability is a key consideration: emphasis on the latter is increasingly important: the strategic adoption of new technology requires comment and review from all stakeholders, an assessment of the process, and inclusion of other attributes such as the degree of behavioral acceptance (Becker & Lindgren, 2011). Others usability factors include how easily the user (i.e., clinician) can interface to the CDSS, assessing user mastery of the CDSS, assessing the impact of the CDSS on work practices, and identification of interactive problems to the CDSS (Kushniruk, 37: 2004).

Objective Measures:

Objective approaches assess the quantitative improvement associated with implementation of the CDSS. There are several approaches that may be taken depending on the goal of the evaluation. Variables include the study setting, the assessment criteria (i.e., speed or temporal improvements), and workflow efficiencies. Objective measures are listed below (AHRQ, 2012).
Objective Measures

<table>
<thead>
<tr>
<th>Approach</th>
<th>Description</th>
<th>Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random Clinical Trials (RCTs)</td>
<td>RCTs evaluate the efficacy of the CDSS application using predefined attributes</td>
<td>• Statistical methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Data mining</td>
</tr>
<tr>
<td>Performance Measurement</td>
<td>Direct measurement of performance scores</td>
<td>• HEDIS measurement set</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(numerator &amp; denominator)</td>
</tr>
<tr>
<td>Patient Outcomes</td>
<td>Clinical evaluations of improvements in patient outcomes based on application of the CDSS guidelines</td>
<td>• Statistical methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Quality Reporting Initiatives</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Data mining</td>
</tr>
<tr>
<td>Design Studies</td>
<td>Diagnostic efficacies and treatment measurements to established or emerging gold standards of care</td>
<td>• Comparative effectiveness</td>
</tr>
<tr>
<td></td>
<td>Temporal study measures compared to prior methodologies and post implementation results</td>
<td>• Decision Trees</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Probabilistic Engines (Bayes')</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Statistical methods</td>
</tr>
<tr>
<td>Quality Scoring</td>
<td>Improvements in quality of care, reduced Adverse Medical Events (AMEs), and hospital re-admissions</td>
<td>• Statistical methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Quality Reporting Initiatives</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Data mining</td>
</tr>
<tr>
<td>Technical Characteristics</td>
<td>Usability, extensibility, scalability, reliability, availability, maintainability</td>
<td>• Statistical methods</td>
</tr>
<tr>
<td>Economic</td>
<td>Revenue Cycle Management System (RCMS) impacts</td>
<td>• Dashboard reporting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Financial accounting</td>
</tr>
</tbody>
</table>

Table 3

Subjective Measures:

Subjective approaches assess both quantitative and qualitative improvements associated with implementation of the CDSS. The table below highlights some of the approaches.

<table>
<thead>
<tr>
<th>Subjective Measures</th>
<th>Description</th>
<th>Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Studies</td>
<td></td>
<td>• Statistical methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Report based</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Compliance to safety goals and requirements (i.e., TJC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• HIPAA and HITECH (security and privacy)</td>
</tr>
<tr>
<td>Contextual Factors</td>
<td>Adoption, acceptance, and value proposition (physician, clinician, and nursing acceptance)</td>
<td>• Survey methods</td>
</tr>
</tbody>
</table>

Table 4

Stage II assessments are often used to assess the clinical efficacy of CDSS (Kaplan, 2001) (Shortliffe & Cimino, 2006). Specifically, such assessments measure the effect of a knowledge system on the process of care. Thus, in order to effectively evaluate the CDSS, several Stage II
assessments may need to be performed. Specifically, three Stage II assessments shown in the table below are proposed (Kaushal & Bates, 2001).

<table>
<thead>
<tr>
<th>Stage II Assessments</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple case studies with physicians, clinicians, nurses, and patients</td>
<td>Provision of clinical guidelines and clinical outcomes</td>
</tr>
<tr>
<td>Evaluating CDSS efficacy using data mining techniques promulgated on data warehousing and OLAP</td>
<td>Statistical analysis and synthesis</td>
</tr>
<tr>
<td>Controlled Studies measuring key clinical performance measures</td>
<td>Statistical methods</td>
</tr>
</tbody>
</table>

Table 5

**Discussion**

*To the Core* provides real-time interaction with clinicians at the point of care, which ultimately improves clinical outcomes, quality of care, and timeliness of care. Using a standards-based approach, *To the Core* provides interoperability across a continuum of communications, whether machine-based or human based. Both competitive and clinical advantages are realized by automating performance measurement while capitalizing on MU initiatives such as EMRs and continuity of care. Indeed, industry opinion leaders routinely point out that “standardizing quality measure data elements and logic will streamline implementation of measures and reduce the burden of manual data collection and reporting” (Ribick, 2009). And, “implementation of nationally-recognized and endorsed quality measures will play an important role: … standardization will be critical in making quality improvement efforts useful and meaningful for physicians and other clinicians, and for improving the health of America’s patients” (Ribick, 2009). In this context, “the appropriate decision is not whether to design and implement a CDS” but how to design and implement it so that it “makes it easy to do the right thing” (Berner E. S., 2007). The industry recognizes that a well designed and implemented CDS holds “great potential to improve health care quality and possibly even increase efficiency to reduce health care costs” (Berner E. S., 2007).

Several implementation issues are expected. First, required adjustments are anticipated, particularly during beta testing. To manage this, the implementation team will have an actual physical presence in the ED and on the pulmonary floor. All issues discovered during this period will be discussed and addressed using meetings and other feedback mechanisms to quickly resolve noted issues. Second, direct uploading of Core Measures directly to TJC and CMS is not supported. Direct uploads require regulatory and safety approvals, and the length of time required to secure regulatory approval is unknown since this is likely the first application of its kind. Use of a third party (i.e., data warehousing) is an available option to the HCO until this issue can be more fully investigated. Last, knowledge updates are not in a machine-downloadable format (either from TJC or CMS). Accordingly, *To the Core* requires some level of manual intervention. This is sub-optimal, as it may lead to potential programming errors. A possible solution is to employ industry champions such as the American Hospital Association (AHA) and/or the American Medical Association (AMA) to drive industry change in order to automate the update process.

In conclusion, *To the Core* promises to greatly improve the safety, efficiency, and efficacy of HCO clinical and administrative operations. It improves patient safety via the interactive nature of the CDSS, assures compliance-based reporting of Core Measures, increases HCO revenues through substantiation of quality programs, enhances clinical and administrative workflows, and lowers operating expenses (via process improvements). Additionally, the implementation of *To the Core*
in Outpatient Quality Reporting (OQR) programs can directly increase HCO revenue cycles, since submission of CMS OQR data drives HCO reimbursements based on qualifying Outpatient Prospective Payment System (OPPS) payment schedules that are keyed to Core Measure performance reporting: HCOs submit data for 23 quality measures consisting of 14 clinical performance measures, 7 Imaging Efficiency Measures, and 2 Web-based Structural Measures (Hospital Outpatient Quality Reporting (OQR) Program Overview). Thus, *To the Core* is expected to become an integral part of HCO operations from the standpoint of clinical performance excellence for those organizations willing to rise to the challenge.
Works Cited


JointCommission.org:
http://www.jointcommission.org/specifications_manual_for_national_hospital_inpatient_quality_measures/
Appendices

1 – PN-3a Decision Tree Logic

Blood Cultures Performed within 24 Hours Prior To or 24 Hours After Hospital Arrival Who Were Transferred or Admitted To the ICU Within 24 Hours of Hospital Arrival. (The Joint Commission, 2011)

**Numerator:** Number of pneumonia patients transferred or admitted to the ICU within 24 hours of hospital arrival who had blood cultures performed within 24 hours prior to or 24 hours after at the hospital.

**Denominator:** Pneumonia ICU patients 18 years of age and older.

---

Variable Key:
- Duration of Stay
- ArrivalDateTime
- InitialBloodCultureDateTime
- InitialBloodDay
- InitialBloodMinutes

---
Note: InitialBloodDay=0 means blood culture date was day 0, an arrival date. If it is within 24 hours, we need the exact time.
2 – PN-3b Decision Tree Logic

Blood Cultures Performed in the Emergency Department Prior to Initial Antibiotic Received in Hospital. (The Joint Commission, 2011)

**Numerator:** Number of pneumonia patients whose initial ED blood culture was performed prior to the administration of the first hospital dose of antibiotics.

**Denominator:** Pneumonia patients 18 years of age and older who have initial blood culture collected in the ED.

---

**Variable Key:**
- Antibiotic Timing
- Blood Culture Timing
- Blood Culture Collection Day
- Duration of Stay
- Initial Antibiotic Date
- Initial Antibiotic Time

---

Flowchart showing the decision tree logic for PN-3b.
**Non-UTD Value for at least one antibiotic dose**

- **Initial Antibiotic Date**: The Antibiotic Administration Date that corresponds to the initial antibiotic dose.
  - **Note**: The initial antibiotic dose is the earliest antibiotic dose administered first as on Table 2.1.
  - If there is more than one antibiotic on the earliest date, select the one having the earliest non-UTD Antibiotic Administration Time.
  - If there is only one antibiotic on the earliest date, then the earliest antibiotic dose is the Initial Antibiotic Dose.

**Blood Culture Collection Day (in days)** = Initial Antibiotic Date minus Initial Blood Culture Collection Date

**Non-UTD Value**

- Initial Blood Culture Collection Date ≤ 0: days

- Initial Blood Culture Collection Date = 0: day
  - Antibiotic Administration Time = UTD for the antibiotic considered the Initial Antibiotic Date

- Initial Blood Culture Collection Date > 0: day
  - Antibiotic Administration Time = UTD for all antibiotics involved

- Antibiotic Grid Not Populated

- Antibiotic Name

- On Table 2.1

- Antibiotic Administration Date

- Antibiotic Name

- Initial Antibiotic Date

- Initial Blood Culture Collection Date

- Blood Culture Collection Day

- Antibiotic Administration Time
Initial Antibiotic Time = The Antibiotic Administration Time that corresponds to the initial antibiotic dose.

Initial Blood culture Collection Time

Non-UTC Value

Antibiotic Timing = Initial Antibiotic Date and Initial Antibiotic Time minus Arrival Date and Arrival Time (in minutes)

< 0 minutes

Antibiotic Timing

≥ 0 minutes

Blood Culture Timing = Initial Antibiotic Date and Initial Antibiotic Time minus Initial Blood Culture Collection Date and Initial Blood Culture Collection Time (in minutes)

< 0 minutes

In Measuring Population

≥ 0 minutes

Not In Measuring Population

In Numerator Population

STOP
3 – PN-6a Decision Tree Logic

Initial Antibiotic Selection for Community-Acquired Pneumonia (CAP) in Immunocompetent Patients. (The Joint Commission, 2011)

**Numerator:** ICU pneumonia patients who received an initial antibiotic regimen consistent with current guidelines during the first 24 hours of their hospitalization.

**Denominator:** ICU pneumonia patients 18 years of age and older.

---

**Variable Key:**
- Duration of Stay
- Antibiotic Days
- ANTIMINUTES
- Absent Flag

---

**Diagram:**

- **START**
- Run cases that are included in the PN Initial Patient Population and pass the edits defined in **Transmission Data Processing Flow** Clinical through this measure.

- **Chest X-Ray**
  - Missing
  - A: 2, 3

- **Confirm Measures Only**
  - Missing
  - = 2, 3, 4

- **Clinical Trial**
  - Missing
  - = N
  - X

- **PN&6c**
- **H**
Note: The front-end edits reject cases containing invalid data such as an incomplete Antibiotic Grid. A complete Antibiotic Grid requires all rows in the row to contain either a valid value or "ND".

For each case, include for further processing only those antibiotic doses that are on Table 2.1 and whose associated route is 1, 2, or 3.
Initial Antibiotic Selection For Community-Acquired Pneumonia (CAP) In Immunocompetent Patients – Non Intensive Care Unit Patients. (The Joint Commission, 2011)

Numerator: Non-ICU pneumonia patients who received an initial antibiotic regimen consistent with current guidelines during the first 24 hours of their hospitalization.

Denominator: Non-ICU pneumonia patients 18 years of age and older.

Variable Key:
- Patient Age
- Duration of Stay
- Antibiotic Days
- Antibiotic Reg
- Antimicutes
Note: The front-end edits reject cases containing invalid data and/or an incomplete Antibiotic Grid. A complete Antibiotic Grid requires all data elements in the row to contain either a valid value or "UTD".

---

For each case, include for further processing only those antibiotic doses that are on Table 2.1 and whose associated route = 1, 2, or 3.
Note: When checking for route of antibiotic, check ONLY for the corresponding antibiotic. For example, if an antibiotic on Table 2.9 was received by the patient, check if route was appropriate for that antibiotic only.