Care Coordination: Formalization of Pathways for Standardization and Certification

Report for Project: Health System Modeling and Simulation: Coordinated Care Example

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Abstract

We review the Pathways Community "HUB" model and provide a formalization of Pathways that serves as a basis for quality improvements in coordination of care involving computerized support for better Pathway reporting, improved client adherence to their assigned activities, and improved coordination among the payers and agencies involved. Recently developed Standards for Community HUB Certification include requirements for compliance to standard Pathway specifications, although such specifications are not included in the current draft. The formalization proposed here provides a firm basis for such specifications. More generally, formalization provides a firm basis for capitalizing on the transparency that is afforded by the Pathways Model which enforces threaded distributed tracking of individual patients experiencing Pathways of intervention, thus supporting coordination of care and fee-for-performance based on end-to-end outcomes. We show how metrics can be defined based on the formalization that, when applied to data from an actual HUB, provide insight into the effectiveness of the HUB, the means to measure such effectiveness, and its dependence on various factors of HUB operation.

Introduction

U.S. health care, the most expensive in the world, has been described as an assemblage of uncoordinated component subsystems embedded in a market economy that promotes price setting by components independently and without reference to the end-to-end quality of care (and related costs) delivered to patients. This paper is one of the reports generated by a research project [1] to develop a modeling and simulation methodology and tools to capture the existing state of, and re-engineer, the health care "system of systems" to increase quality of care and reduce cost. Stimulated by the Affordable Care Act (ACA) and other initiatives, efforts are underway to increase the level of information technology (IT) to improve patient recordkeeping and portability as well as the move to price service based on performance rather than amount provided. Yet such an IT infrastructure by itself will not provide significantly greater coordination since it does not provide transparency into the threads of transactions that represent patient treatments, their outcomes, and total costs.

Care coordination is the organization of care activities among the individual patient and providers involved in the patient's care to facilitate the appropriate delivery of health care services. This paper focuses on the Pathways Model of care coordination [2, 3], a construct that enforces threaded distributed tracking of individual patients experiencing certain Pathways of intervention, thereby supporting coordination of care and fee-for-performance based on end-to-end outcomes.

Community care coordination works at the community level to coordinate care of individuals in the community to help address health disparities including the social barriers to health. Leath and Mardon [4] reported on a study that defined performance measures and tested them at several community care coordination sites. The project addressed the lack of performance measures in community care coordination and assessed, to some extent, the usefulness of the measures in helping to inform local quality improvement activities. The study found that in many cases documentation on which quality improvement could be based was scarce and that client adherence to recommended activities was problematic.

The explicit formulation of problem resolution processes, an essential element of the Pathway Care Coordination concept, opens up possibilities for system level metrics and analytics. These enable more coherent visualization of system behavior than previously possible and thereby foster greater process control and improvement re-engineering, This paper reviews the Pathways Model and provides a formalization of Pathways that serves as a basis for quality improvements in coordination of care involving computerized support for better Pathway reporting, improved client adherence to recommended activities, and improved coordination among the payers and agencies involved. Recently developed Standards for Community HUB Certification [5] include a requirement for compliance to standard Pathway specifications, although such specifications are not included in the current draft. The formalization proposed here can provide a firm basis for such specifications.

The aim of this report is to describe an initial formalization of Pathways to support standards for community HUB certification. We explain how this formalization came about, requirements for formalization to support standards, explication of the Pathway concept, and Pathway formalization and its implication for Community HUB certification and operation. We also discuss some results of analysis using the metrics defined based on the formalization. Traditional approaches employ reduction in low birth rate as the relevant measure of Pathway effectiveness. However, we found that the percentage of normal births is the more informative metric. We examined how outcomes vary in client subsets such as those based on race and age, as well as those derived from external sources of clients. The results highlight the importance of keeping programs at the community level where clients can be identified and enrolled early in pregnancy to receive the most intervention. The results also throw light on how benchmark-based payment, risk-scoring policies, and administrative delays in enrollment can strongly influence coordinator and client performance, and, therefore, pregnancy outcomes. We conclude the report with a discussion of how the Pathways Model and its formalization will enable exploiting the emerging national IT infrastructure to afford significantly greater coordination of care and fee-for-performance based on end-to-end outcomes.

Background: Origins of Formalization

An Agency for Healthcare Research and Quality/National Science Foundation workshop [6] envisioned an ideal health care system that is unlike today's fragmented, loosely coupled, and uncoordinated assemblage of component systems. The workshop concluded that, "An ideal (optimal) health care delivery system will require methods to model large scale distributed complex systems." Improving the health care sector presents a challenge that has been identified under the rubric of Systems of Systems engineering [7], in that the optimization cannot be based on sub-optimization of the component systems, but must be directed at the entire system itself. People with multiple health and social needs are high consumers of health care services, and are thus drivers of high health care costs. The ability to provide the right information to the right people in real time, requires a system-level model that identifies the various community partners involved and rigorously lays out how their interactions might be effectively coordinated to improve care for the neediest patients whose care costs the most.

The overarching objective of our research is to demonstrate a modeling and simulation methodology and framework to model the entire health care system as a loosely coupled distributed system [8, 9]. The approach is to tackle a particular instance of such a framework through application to coordinated care. The initial goal was to develop a prototype of such a system model, as envisioned by the workshop, as an end in itself, and also to demonstrate the applicability of the framework to myriad other health information technology (IT) problem areas. The criteria for such a model are that it should be:

- Flexible to meet variety of stakeholders' interests and variety of accountable care implementations.
- Scalable to accommodate increases in scope, resolution, and detail.
- Integrated as a system of systems concept: system, components, and agent-based concepts extended to human behavioral limitations.
- Enhanced with electronic medical records and health IT systems as needed to support coordinated care.
- Supported with services based on the model, e.g., patient tracking, medication reconciliation, and so forth.

Such a model will show how to systematically represent the behaviors of patients who require coordinated care interventions and the providers of such coordination services. This will render such behaviors amenable to health care system design and engineering. The Community Pathways Model was developed by the Community Health Access Project (CHAP) in Richland County, Ohio to improve health and preventive care for high-risk mothers and children in difficult-to-serve areas. CHAP has been in operation since 1998. In Ohio, low birth weight (LBW) births represent only about 10 percent of all Medicaid births but account for more than 50 percent of all Medicaid birth expenditures.

To focus model development and to enable data access for calibration and validation, CHAP agreed to work with the authors of this paper the test bed for our model development. CHAP was formed to focus on pregnant women at risk of poor birth outcomes, and its Pregnancy Pathway was enhanced to work as a common outcome measurement tool in the seven community agencies designed to identify and engage pregnant women [2]. Agency contracts were changed in 2005 to begin paying for specific benchmarks along the Pregnancy Pathway with the highest payment provided for a normal birth weight infant. This pilot HUB still exists in Richland County and remains focused on pregnant women and young children at risk. The Pathways that are currently used and contracted for with Medicaid managed care plans (MCPs) include: Pregnancy, Postpartum, Family Planning, Medical Home, Medical Referral, Developmental Screening and Referral, and Immunization Screening and Referral. There are three MCP contracts that vary in both the Pathways they support and the reimbursement rates for each Pathway. The county-wide low birth weight rate has decreased from 9.7 percent in 2005 to 8.0 percent in 2008 (Ohio Department of Health Data Warehouse). CHAP successfully demonstrated how the Pathways Community HUB Model worked with high-risk pregnant women in Richland County to improve both health outcomes and cost savings.

In the Community HUB Care Framework, the Pathways system serves as the documentation and reporting tool that captures (but does not represent in a formal manner) each of a set of guiding principles—finding those at risk, ensuring that they are treated with evidence-based medical and social interventions, and measuring the health outcomes and costs of these efforts. These basic principles are applicable to the full range of coordinated care efforts. The Pathways documentation and reporting system, enhanced to work as a common outcome measurement tool, has been extensively employed by CHAP to identify and engage women with high-risk pregnancies. Our use of CHAP as a test bed offers the advantage of a concrete instance of Pathways Community HUB care coordination with sufficient test data for model validation. Moreover, since the Pathways Community HUB Care Framework encapsulates the basic principles of coordinated care, starting with CHAP as an instance (example?) helps to formalize these principles within the proposed systems-level simulation for developing and testing coordinated care service architectures in general.

CHAP, under its executive director, agreed to provide access, under suitable data-sharing agreements, to its database of client and Pathway records. In the initial phase, our objective was to construct and validate the model when applied to high-risk mothers and children in difficult-to-serve areas following the CHAP coordinated care Pathways. We collected de-identified personal health and behavioral data (such as demographic, socioeconomic, and so forth) for successfully and unsuccessfully treated clients from the electronic health record (EHR) database employed by CHAP. As with earlier studies [4, 10] we encountered data quality problems which led to development of specific metrics and tools to assess data quality and maximize its usefulness. Data quality issues are discussed in Appendix B and in another report [11]. Consulting with the CHAP participants in the project, it became apparent that the metrics and tools developed would be useful to implementations of the Pathways Model independently of their use in our data analysis. We also realized that these tools would enable us to compare output of the model to be developed with actual CHAP data at a more in-depth level and more extensively than initially contemplated (We originally intended to validate the model by comparing its predictions in selected scenarios with actual outcomes extracted from available data.) These factors motivated the presentation described here.

Requirements for Pathway Formalization

Standards for certifying Community HUB programs are being developed by the Rockville Institute in collaboration with CHAP and other Pathway-based community coordinated care organizations [5]. The standards include prerequisites for a community-based organization to become a recognized HUB. The potential HUB must meet standards in the areas of governance and administration, organizational infrastructure, client identification and enrollment, scope of services, and accountability. In addition, standards are specified for the Care Coordination Agency that is responsible for engaging and enrolling at-risk individuals. Many of these prerequisites and standards explicitly or implicitly imply requirements for compliance to standard Pathway specifications, or would be greatly enhanced by having such standards to reference. For example, the prerequisites for a potential HUB include that its operation be based on the Pathways Community HUB model and that it has the ability to track outcomes using standard Pathways and tie measured outcomes and results to dollars within financial contracts with payers.

Scope of service standards include the requirement that the HUB utilize Pathways from a list of Pathways and service codes to be provided. The Care Coordination Agency must have a Quality Improvement Plan and performance measures that are monitored and used to inform quality improvement planning. It must have financial contracts that link payments to accomplishment of Pathways care coordination milestones and a systematic method for tracking and monitoring client services and care coordination service program performance. The agency's data infrastructure is allowed to employ either paper-based manual or automated tracking to report on the number and type of clients in total and per care coordinator, Pathways completed by type, for agency, per care coordinator, and per client, and Complete, Finished Incomplete and Pending Pathways (defined below). Although Pathway standards are not included in the current draft, the intention of the developers is to include such standards as an integral part of the whole. The formalization proposed here can provide a firm basis for such standardization and the implications for making it easier to formulate and satisfy other HUB and Care Coordination Agency standards. Table 1 illustrates how selected system metrics and formalization are mapped to particular HUB certification standards. Such mapping leads to improved standardization of processes, system performance, and outputs.

Table 1. HUB certification standards, metrics, and formalization

HUB certification standards	How system metrics and formalization can help
HUB utilizes Pathways from a list of standard Pathways.	Standard Pathways could be defined using the formalization developed in this paper. This would provide a well-defined means for a uniform description of such basic Pathways. The same uniform basis can be used for new Pathways as they are introduced in practice. Duplication and overlap could be controlled programmatically.
The Care Coordination Agency must have a Quality Improvement Plan and performance measures that are monitored and used to inform quality improvement planning.	Performance measures can be defined based on the system metrics such as those that are discussed in the section on outcome metrics based on the formalization.
The agency must have financial contracts that link payments to accomplishment of Pathways care coordination milestones and systematic method for tracking and monitoring client services and care coordination service program performance.	Pathways care coordination milestones are explicitly included in the end states of the formal models, which facilitates tracking, monitoring, and linking to payments. The sections on reporting competence and client adherence expand on this facilitation.
The agency's data infrastructure is allowed to employ either paper-based manual or automated tracking to report on the number and type of clients in total and per care coordinator; Pathways completed by type, for agency, per care coordinator, and per client; and Complete, Finished Incomplete and Pending Pathways.	The section on supporting HUB data infrastructure discusses a web service based on Pathways formalization.

Review: Formulating and Defining Pathways

The Pathways Model is a tool that can coordinate the activities of otherwise uncoordinated agencies and services by focusing on the progress and outcomes of individual clients as they traverse such care organizations. As the Pathways Model is deployed to improve community health and social service outcomes, basic regional needs assessments, geo-mapping, and other data are evaluated to determine the areas of greatest need. The information required for these evaluations is readily available and often duplicative in many communities. As a result of these evaluations, Pathways can be chosen to specifically address the highest priority health and social outcomes.

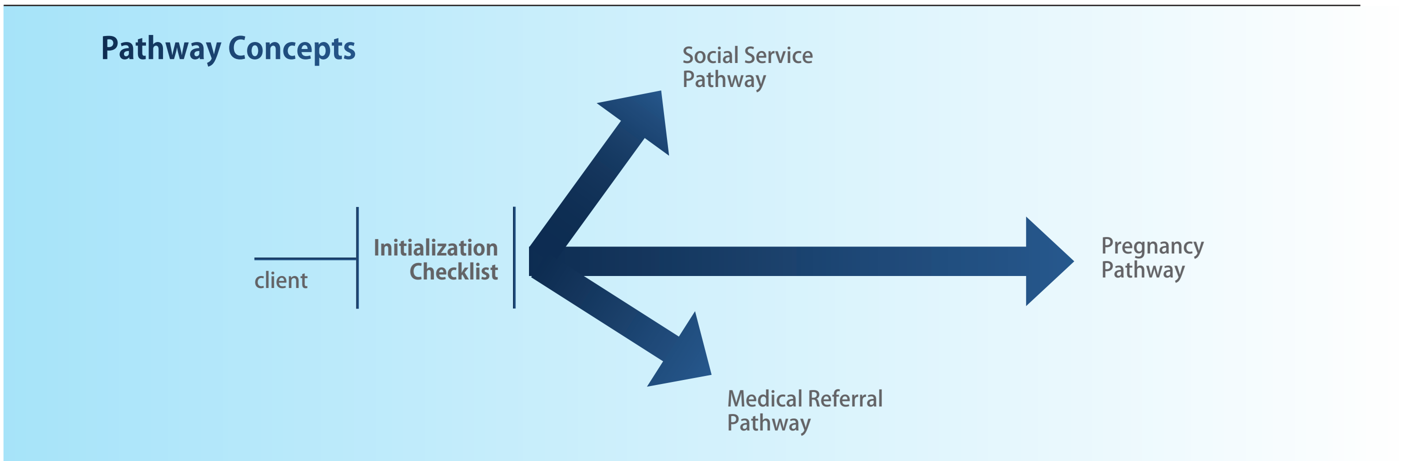
Pathway Concept

Pathways are unique in that the outcomes are tracked at the level of the individual being served. Each step of the Pathway addresses a clearly defined action towards problem resolution. Many steps deal with social and cultural issues, and these steps are just as important as the traditional activities of the health and human service systems. Pathways have been developed for many issues, including homelessness, pregnancy, medical home, immunizations, lead exposure, childhood behavior issues, just to name a few. One client (or patient) may be assigned to many different Pathways depending on the problems identified. At first glance, Pathways may resemble clinical guidelines or protocols; clinical pathway equivalents are discussed in Appendix A.

Coordinated care Pathways are, however, different from clinical protocols and pathways in two essential dimensions: accountability and basis of payment. In a protocol, accountability is not taken into consideration in a specific sense. If the patient does not show up for follow-up appointments or the medication isn't being taking correctly, then the provider is not held accountable as long as he or she followed the protocol. This is not the case in a Pathway. The Pathway is not considered complete until an identified problem is successfully resolved. Conversely, at some definitive point, a Pathway that has not been successfully completed must be closed in a documented fashion. Moreover, as indicated above, coordinated care Pathways are associated with payment for specific benchmarks along the pathway with the highest payment provided for successful outcomes at completion, thereby linking payments to accomplishments. As we shall see, care coordination pathways attempt to be analogous to skeletons showing paths and benchmarks rather than detailed handbooks of actions to achieve these benchmarks.

Upon enrollment a client is interviewed with a checklist of questions that determine the set of Pathways to be initiated. Pathways are pre-defined threads of transactions that the client is encouraged to carry out to achieve certain subgoals to improve the prospects of attaining the main goal. Pathways can co-exist concurrently as illustrated in Figure 1. Pathways may be initiated and terminated as conditions require.

Figure 1. Illustrating the Pathway concept



Pathway: Initiation, Action, Completion, and Closure steps

The structure of a Pathway is summarized in Table 1. The following paragraphs discuss each type of step in the structure.

Completion Step

Pathways are built from the objective back to the initiation. The Completion Step is the successful resolution outcome of an identified problem. This outcome must be a variable that can be measured. The Completion Step is clearly defined, easy to measure, and based on accepted criteria. When an agency or community meets to select Pathways, the first task is to prioritize what the desired, measurable outcomes will be.

A Pathway is not complete until the problem has been resolved. The Completion Step documents that the client has achieved all requirements for confirmed resolution or definitive improvement of the problem identified in the Initiation Step. The Completion Step clearly defines the desired positive outcome. Particular qualifiers of the Completion Step may be required.

These qualifiers may be stated as part of the Completion Step or be further described in the quality assurance manual that supports the Pathways process. Examples follow:

- In an Employment Pathway, the client must remain employed for one month before the Pathway is documented as completed.
- In the Pregnancy Pathway, the baby must be viable and weigh at least 2500 grams at birth. Completion Steps must result in a defined positive outcome. For example,
- A client's receipt of a flyer on smoking cessation provides no evidence that this represents any defined positive outcome. The client must achieve some clear decrease in smoking or complete a training/treatment process that has been proven through evidence-based mechanisms to decrease smoking.
- If a client has been given bus tokens and a medical referral, these alone do not define positive outcomes, unless it is confirmed that the client was actually seen by a medical provider.

Closure Step

A Finished Incomplete Pathway defines a Pathway that has no further work to be done. The Pathway is removed from the client plan without reaching the desired positive outcome. Examples of Finished Incomplete Pathways would include a pregnant woman delivers a low birth weight baby; a family refuses to immunize its child; an unemployed client fails to show up consistently for work. Finished Incomplete Pathways are unfortunate, but a necessary part of the outcome production model. They occur particularly in client populations that are difficult to track and where clients move or change service providers frequently. They can provide a rich source of data to focus on barriers to the outcome production model.

It was quickly recognized that not all Pathways would be successfully completed and that for recording purposes it would be important to officially recognize a negative outcome. Thus an alternative to the completion step was added with an appropriate closure condition that would enable the tracker to close out the Pathway. Clearly the closure criteria must be well-considered. For example, a "time out" condition is based purely on the lapse of a set amount of time without achievement of the objective. Such time outs apply to keeping of a variety of doctor's and other appointments. Such a time out can mark the closure of a Pregnancy Pathway for a client who has left the system for some reason unknown to the tracker. On the other hand, the birth of a baby below 2500 grams is a definite event that marks the end of the Pregnancy Pathway and provides a closure step. Having one of, but not both, a documented completion and closure step, is critical to being able to assess the effectiveness of a Pathway application because otherwise there is irreducible uncertainty in the proposition of positive outcomes relative to the total. Furthermore, documented closure of Pathways supports diagnosis of what might have been responsible for a negative outcome. Further, closure of a Pathway in the hands of one agency may then give another agency a chance to complete the same Pathway (see discussion of coordination below).

Initiation Step

Once the Completion Step is clearly defined, the next Pathway step to be built is the Initiation Step. The specific problem to be addressed, as well as the target population, is identified in this first step. The Initiation Step must clearly define who meets the criteria for the Pathway. It is critical that the Initiation Step and Completion Step be carefully defined in order to maintain the accountability and credibility of the Pathway. The information included in the Initiation Step may be further qualified by the quality assurance manual or guidelines. The Initiation Step must be easy to understand and specific as to the manner of documentation. In some cases, the Initiation Step is very straightforward, such as the client is unemployed or is pregnant. Some Pathways benefit from the utilization of national guidelines or rating scales to define problems, such as out of control diabetes, hypertension, obesity, etc. Resolution of the identified problem will be documented in the Completion Step and the connection between Initiation and Completion must be clear.

Action Steps

The next series of Pathway steps are termed Action Steps. These steps are evidence-based interventions that build upon one another leading to a positive outcome. There may be up to five Action Steps before reaching the Completion Step. More than four or five Action Steps causes the model to lose strength in simplicity and increases the documentation requirements. When significantly more Action Steps are needed, more than one Pathway may be needed. The Action Steps are ordered by priority. For example, if the first step in getting a child's immunizations up to date is believed to be educating the family about the importance of immunizations, then that should be the first Action Step. When the Pathways Coordinator/Community Health Worker is working through the Pathway steps, the Action Steps may not be completed in series (one after the other). One of the key features of Pathways reporting is finding the steps that took the longest to complete. These rate-limiting steps are the ones that may be delaying or restricting the Pathways process. Addressing issues related to the rate-limiting-steps will often improve the outcome production process.

Table 2. Pathway structure

Initiation step **Action steps**	Defines the problem and target population Examples: High risk pregnancy, asthma in poor control, lack of medical home, etc. • Provide standardized education to the client/family regarding the problem identified • Identify and develop a plan to eliminate identified barriers to receiving services related to the problem • Assist client/family in identifying qualified provider or agency to resolve identified problem. This may include scheduling appointment, arranging transportation, submitting forms, etc.
Completion step	• Must be measurable outcome. • Confirm resolution or significant improvement of identified problem (i.e., normal birth weight, improved control of diabetes, immunizations up to date) or • Confirm that client is receiving an evidence-based service proven to be effective in resolving or improving the identified problem (i.e., smoking cessation program). Conditions, including time outs that apply to justify closing a Pathway in the absence of successful completion via completion criteria.

Example: Pregnancy Pathway

The Pregnancy Pathway offers an example. As discussed in more detail below, steps are represented symbolically and stand for events in the pregnancy process, as depicted in Figure 2. Some further explanation is needed. The PREG1 and PREG2 steps must occur exactly once for each enrolled client. PREG1 occurs at, and records the date of enrollment with the community care coordinator. PREG2 follows PREG1 as a step but may have an earlier date referring to the date at which the client first consulted with a physician concerning a pregnancy. The completion step PREG4 documents a successful outcome with a normal birth weight while step PREG5 documents a low birth weight outcome, PREG6 is the closure step which, as described above, indicates the date at which the Pathway was closed without a known outcome.

Figure 2. Steps in the pregnancy process

PREG1	Pregnancy initiation date
PREG2	First prenatal appointment date
PREG3	Kept prenatal appointment date
PREG4	Delivery date, with weight ≥ 2500 grams
PREG5	Delivery date, with weight < 2500 grams
PREG6	Pregnancy Pathway finished incomplete

Initialization Checklists

In addition to the release of information form, there are data collection forms that are key to deciding on services needed by the client and coordination of the agencies that provide such services. The Pathway Community HUB model is an extension that supports a higher level of coordination among agencies. As shown in Figure 1, an enrollment form developed by collaborative agencies captures the key pieces of information that all agencies will need, such as demographics, the agency enrolling the client, and date such information is submitted to the Community HUB. This form also serves as a request to initiate Pathways, with the submitting agency indicating which Pathways it would like to initiate. The HUB reviews the community database to determine if another agency is already working with that client on the issues identified.

CHAP Pathways and Implementation

For reference later, the list of the 17 pathways currently employed by CHAP is given in Table 3 with details provided in Appendix C.

Current Implementation and Its Limitations

Before plunging into a formal representation, we discuss an implementation of Pathways employed by CHAP as implemented by NetSmart, an electronic health record (EHR) systems provider. In a relational database, each client has a unique identification number (ID), serving as primary key to tables with fields of demographic data, as well as responses to initiating interview questions as well as notes entered by CHWs after home visits. As illustrated in Figure 2, codes are used for Pathway steps, where an alphabetic prefix denotes the type of Pathway (e.g., PREG) and a numerical suffix denotes a step in the process (e.g., PREG3 denotes step 3 in the Pregnancy Pathway.) When documenting a step, a user interface enables a CHW to enter a row in a table with the client ID as key and the code for the step, the date of the related event, and descriptive information as corresponding field values.

Table 3. CHAP pathways

BEH	Behavioral Referral Pathway
DEVR	Developmental Referral Pathway
DEVS	Developmental Screening Pathway
EDU	Education Pathway
FAMP	Family Planning Pathway
IMMR	Immunization Referral Pathway
IMMS	Immunization Screening Pathway
INS	Health Insurance Pathway
LEAD	Lead Pathway
MANAGE	Medication Assessment Pathway
MED	Medication Management Pathway
MEDHOME	Medical Home Pathway
MEDREF	Medical Referral Pathway
POSTP	Postpartum Pathway
PREG	Pregnancy Pathway
SMOKE	Smoking Cessation Pathway
SSREF	Social Service Referral Pathway

Our extraction of data for analysis revealed a number of limitations in the NetSmart implementation. Most relevant to this report is the absence of support for data entry that requires accurate and complete entry of Pathway events as they occur in interacting with the client. The formalization and associated proposed implementation of the Pathways Model address these limitations with the intention of providing a design for an improved implementation.

Formalization of Pathways

We now discuss formalization of the Pathway concept, motivated by experienced limitations in current CHAP data infrastructure implementation. The earlier stated objective of formalizing Pathways is to support the standards required by Pathways Community HUB Certification. Formalization of Pathways is defined as representing them in a symbolic form that lends itself to manipulation by well-defined logical and mathematical rules. Before proceeding, we briefly review the approach that we take to formalization.

Brief Review of Formal Concepts

Systems theory, especially as formulated by Wymore [12], provides a conceptual basis for formalizing the Pathways concept. Systems are viewed as components to be coupled together to form a higher level system, The Discrete Event Systems Specification (DEVS) formalism [13], based on Systems theory, provides a framework and a set of modeling and simulation tools to operationalized Systems concepts. A DEVS model is a system-theoretic concept specifying inputs, states, outputs, similar to a state machine [14]. Critically different however, is that it includes a time-advance function that enables it to represent discrete event systems in a straightforward platform-neutral manner. DEVS has been widely used within modeling and simulation to design, verify, and implement complex reactive systems [15-19]. DEVS provides a robust formalism for designing systems using event-driven, state-based models in which timing information is explicitly and precisely defined. Hierarchy within DEVS is supported through the specification of atomic and coupled models. Atomic models specify behavior of individual components. Coupled models specify the instances and connections between atomic models and consist of ports, atomic model instances, and port connections. The input and output ports define a model's external interface, through which an atomic and coupled model can be connected to other models or to interact with external users. As an operational software tool for working with the DEVS formalism, the Modeling and Simulation Environment, MS4Me [20] provides an integrated development environment dedicated to the development of DEVS models and simulations. The MS4 Me offers tools to construct such models, test them for correctness, modify them until satisfactory, and simulate or animate them to generate and visualize their behavior.

Atomic Model Representation

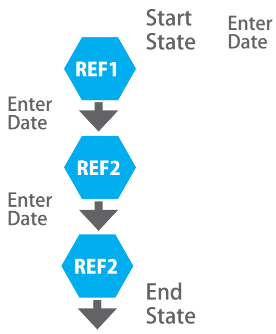
Formalization will proceed by casting Pathways as DEVS Atomic Models [See Appendix C] with implementation in the form of an active calendar that combines event-based control, time management, and database capabilities. More details on the implementation are discussed later in Supporting the HUB Data Infrastructure: A Vision for the Future.

We represent steps in a Pathway as states in a DEVS [See Appendix D] atomic model. Such a representation can constrain steps to follow each other in proper succession with limited branching as required. Moreover external input can represent the effect of a transition from one step to next due to data entry. Moreover, temporal aspects of the Pathways, including allowable duration of steps can be directly represented by the DEVS atomic model's assignment of residence times in states.

We will use the Social Service Referral Pathway (Figure 3) as an example to illustrate the concepts.

Figure 3. Social service pathway and DEVS representation

SSREF1	Social Service Referral initiation date
SSREF2	Social Service Referral scheduled appointment date
SSREF3	Social Service Referral appointment kept
SSREF4	Social Service Referral Pathway finished incomplete



As illustrated in Figure 3, the normal progression through the Pathway begins with a starting state, Ref1, which is the state in which the atomic model is initialized. When a social service referral appointment is made this is considered an external event performed by the CHW and brings the model to state Ref2. When, and if, the appointment is kept by the client, is also considered an external event and brings the model to the end state Ref3, where the Pathway is completed. This is signified by the fact that there are no transitions out of the end state. Dates are associated with the states Ref1, Ref2, and Ref3, documenting when the Pathway was established, the appointment for services was made, and finally kept. In the current implementation, these dates are entered in fields SSREF1, SSREF2, and SSREF3, respectively, of the client's record. In a future implementation, these entries might be automatically "time-stamped" by the atomic model by pulling the current date from the calendar object associated with the application.

Figure 4 shows the atomic model extended to include the end state, Ref4, corresponding to the incomplete step SSREF4. This requires the CHW to close the Pathway via an external transition to Ref4 by entering a date in states Ref1 and Ref2. This should occur when it becomes known that the Pathway will not continue because an appointment will not be made, or because it has not been kept.

Figure 4. Extended DEVS representation

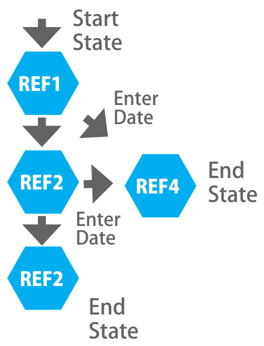
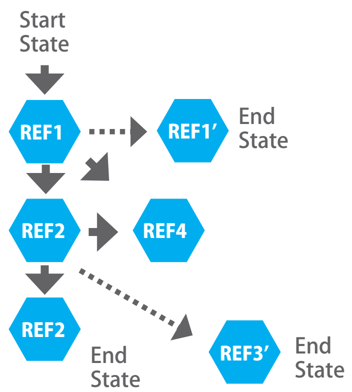


Figure 5 illustrates how formalization can employ the temporal properties of the DEVS atomic model to extend the features of Pathways making them easier to manage. The dashed arrows signify internal transitions of the model which take states Ref1 and Ref2 to Ref1' and Ref2,' respectively. Such an internal transition, or "time out," occurs when the time duration assigned to the state has expired and there has been no external event to transition it to another state. For example, a time out value of 60 days can be assigned to Ref1, which would cause it to close out the Pathway if there is no appointment scheduled within this period. Similarly, the time out value assigned to Ref2 might be computed as the time until the scheduled appointment plus for 10 days after it, which would automatically close the Pathway after a reasonable time without having an external event indicating the appointment was kept to complete it.

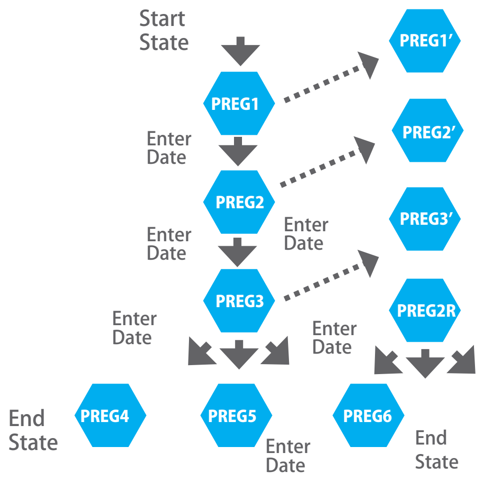
Figure 5. Further extended DEVS representation



Social Service Pathways may repeatedly be re-opened to meet different needs, e.g., food, shelter, child care, etc. In the current implementation, new entries are made with the same field labels but different dates to keep track of such repetitions. In the formalization, we support the creation of new instances of the atomic model to instantiate new Pathways as required.

An atomic model representation of the Pregnancy Pathway is shown in Figure 6. It differs from the social service and other Pathways in that only one instance is created for each client and to allow scheduling and recording repeated prenatal appointments during the life-span of the Pathway. This is represented in the model by the external transition taking the PREG3 state (for a completed appointment) back to the state PREG2R in which another appointment can be made. When (and if) this appointment is kept, the model returns to PREG3 from which the cycle can be repeated. The states PREG3 and PREG2R both have transitions that allow recording the outcome (normal, low birth weight, or unknown) of the Pregnancy Pathway.

Figure 6. DEVS representation of pregnancy pathway



Reporting Metrics Based on Formalization

As will be discussed, counts of Pathway codes and ratios are statistics that can provide client measures of how a client's adherence, i.e., how well a client has followed the steps required of her. However, in our study, we found that such counts can often provide inconsistent results in the current implementation. For example, if a client's record indicates more appointments kept than made, what are we to make of her adherence? Having a formal specification of a Pathway enables us to prove requirements for step code counts of client records resident in the database. Having such requirements, we can filter out records that do not meet such requirements and calculate adherence on the remaining subset. Further the relative size of the remaining set is a measure of how consistent the data set is and by implication how correctly the CHWs are entering data into the database.

Social Service and Other Referral Pathways

Social Service, Medical Referral, Postpartum, and Family Planning Pathways have simple structures involving initiation, appointment making, and appointment keeping.

Examining the state graph in Figure 3 reveals that the only way to get to the appointment kept state, Ref3, is by starting in initial state, Ref1 and traversing through appointment made state, Ref2. Thus, the following relation must be true:

#Ref1 >= #Ref2 >= #Ref3.

where #Ref1 denotes the number of codes of the form Ref1 in a client's record. Applying this relation as a criterion for consistency requires that the CHW to have officially entered a SSREF1 code with date before making an appointment and noting it in an SSREF2, finally entering a SSREF3 to document that the appointment was kept. Examination of the data revealed that often CHWs neglected to enter the SSREF2 but did properly enter the other codes. We realized that the SSREF2 entry is redundant in that it can be implied by the SSREF3 entry (to keep an appointment implies that it had to be made.) Therefore to maximize the filtered data while retaining records of interest, we imposed the following relaxed criteria for consistency:

A client's record is consistent if

#Ref1 >0 and #Ref1 >= #Ref3.

Relative to such a definition of consistency of a client record, we can define the consistency of a set of records as the percentage of consistent records in the set.

Pregnancy Pathway

The Pregnancy Pathway is more complex than the single appointment Pathways in that it has a multiple branching termination that provides information about normal or low birth weight. In this case we are concerned that a Pathway has been properly opened and closed. Referring to Figure 6, we make the definition:

A client's Pregnancy Pathway record is **OpenAndClosed if**

 # PREG1>0 and #PREG4+#PREG5+#PREG6 =1

This requires that the Pathway record has been initiated (# PREG1>0) and that at exactly one of the termination steps PREG4 (normal), PREG5 (low birth weight), or PREG6 (incomplete) has been taken.

The closure of a set of records is then the percentage of Pregnancy Pathway records that satisfy the OpenAndClosed criterion.

For the Pregnancy Pathway we are interested in the records that convey a definite result (normal or low birthweight). This motivates the definition:

A client's Pregnancy Pathway record is complete if

#PREG4+#PREG5 =1

This requires that exactly one entry for either PREG4 or PREG5 has been made.

The completeness of a set of records is then the percentage of Pregnancy Pathway records that satisfy the completeness criterion.

Adherence Metrics Based on Formalization

With the consistency filter producing a subset of reliable records, we can measure client adherence in the Social Service and other Pathways. This leads to the definition for adherence in such Pathways: Adherence of a client in a Social Service Pathway satisfying Figure 5 is measured by:

Adherence = (#ref3 / # ref1) if record is consistent
= 0 otherwise

This defines adherence as the fraction of initiated Pathway repetitions that were successful in keeping appointments (this does not use the number of appointments made as the denominator, per previous discussion).

The adherence of clients in a set of records is the sum of their adherences (as measured) divided by the number of consistent records. Note that if all clients are fully adherent, then the adherence of the set is unity (or 100%).

Results

Consistency and Adherence
The blue (leftmost) bars in Figure 7 show values obtained by applying the consistency metric to the Pathways shown for the data set previously described. There is a large variance between the consistency of the Postpartum Pathway at 86 percent and the others which range from 20 percent and 40 percent. (see Discussion.) The adherence values for the data set as restricted to the consistent subset are shown in the orange (middle) bars. These range from 33 percent to 69 percent (see Discussion). Adherence levels are also shown for the subset of low birth weight (LBW) outcomes in the rightmost (gray) bars. (There are no Postpartum Pathways for LBWs.) While there is little difference between the overall and LBW adherences, there are noticeable differences, in opposite directions, between the Social Service Referral and Medical Referral Pathways (see Discussion).

Pregnancy Pathway Closure and Completeness

Table 4 shows the overall and LBW subsets' measures of closure and completeness. Although both are relatively high levels, the LBW subset has a noticeably higher level (see Discussion).

Figure 7. Consistency and adherence measurements from CHAP data

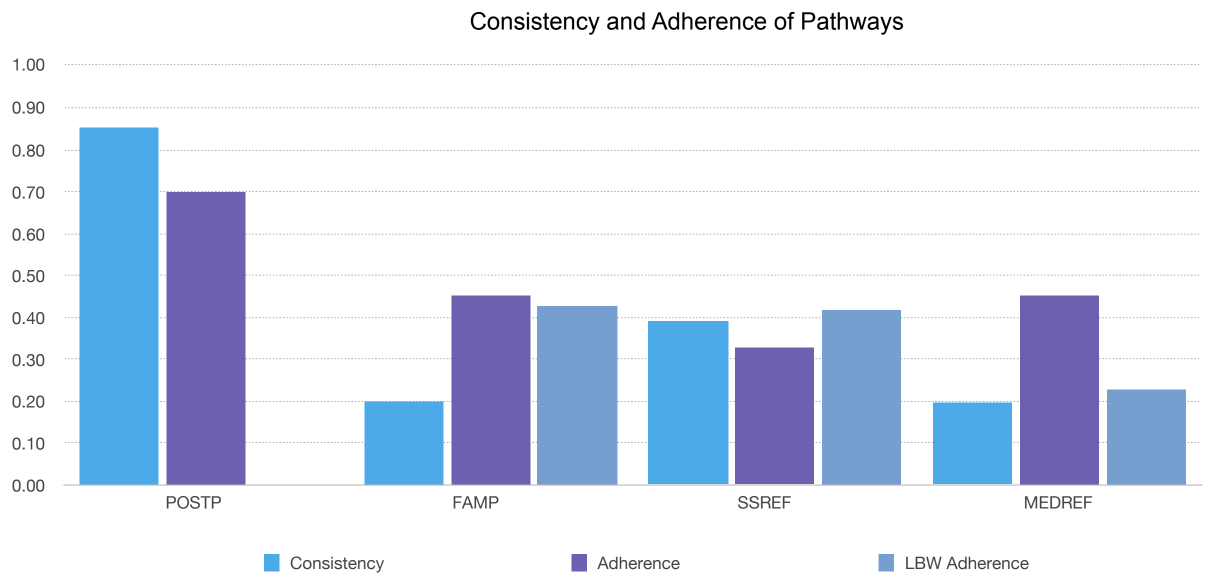


Table 4. Overall and low birth weight (LBW) subsets measures of closure and completeness

	OpenNClosed Fraction	Completeness Fraction
Overall	0.77	0.8
LBW	0.89	0.89

Reporting Competence Analysis

The importance of reporting metrics such as consistency in Pathway reporting has been mentioned above. To summarize, the consequence for data analysis is the more that the data satisfies consistency criteria, the greater the useful data that remains after elimination of the invalid records. For example, at a consistency level of 20 percent for the Medical Referral Pathway, only one-fifth of the records can be used for computing client adherence in that Pathway. Moreover, discrepancy in consistencies values across Pathways can lead to examination of plausible explanations for the observations. For example, the large variance between consistency of reporting for the Postpartum Pathway and the others in Figure 7 called out for an analysis of the CHAP operations that might explain the results. In fact, the Ohio Medicaid Managed Care Plans (MCPs) contract with CHAP to outreach to high risk pregnant members and coordinate their care. The contracts are designed as pay-for-performance with payments tied directly to Pathway completion. The MCPs are most interested in contracting for Pathways that align with HEDIS measures. The Healthcare Effectiveness Data and Information Set (HEDIS) is a tool used by health plans to measure performance. For example, the HEDIS measure for postpartum care is the percentage of deliveries that had a postpartum visit on or between 21 and 56 days after delivery. MCPs contract for the Postpartum Pathway, because it is a measure that is important for their own performance. This graph shows the difference between a Pathway that is linked to payment (postpartum) and three Pathways that are not directly tied to payments (family planning, social service referral and medical referral). If a Pathway is linked to payment, then there are several reviews done at the agency by both the clinical and financial staff. Pathways need to be confirmed—all steps—prior to invoicing the MCPs.

The results for the Pregnancy Pathway in Table 2 indicate a relatively high degree of reporting competence for that Pathway. Since this Pathway is central to CHAP's primary objective of reducing low birth weight outcomes, and its evaluation for this result, the high competence accords with the importance of the Pathway. That the LBW subset indicates a higher competence accords with the observation that the CHWs who care for the population at highest risk for LBW are among the most experienced.

Thus, the reporting competence results suggest that Pathways may receive different levels of reporting attention as a result of several factors. However, perhaps the most surprising result is that the existence of standard and reimbursable metrics for some Pathways may distort the balance of effort to those Pathways, draining effort from other Pathways that are not standardized but may be equally important to attaining the overall objective. Our formalization can contribute to standardizing such Pathways by providing a well-defined basis for defining them and the associated metrics for reporting quality. Furthermore, the ability to monitor CHW effort based on such metrics can support the development of incentive schemes for CHWs that encourage higher levels of reporting. Finally, as shown in Figure 11, <no Figure 11 in this report> the formalization in the form of DEVS models as given above supports implementation of more computerized assistance to CHWs in executing their reporting responsibilities. Many of the mistakes that are possible with the current manual implementation can be obviated with the active calendar implementation that employs atomic model instances to control the possible next steps and provides automatic time outs and reminders on pathway closures.

Client Adherence Analysis

Leath and Mardon [4] reported on a study which defined performance measures and tested them out at several community care coordination sites including CHAP. The project addressed the lack of performance measures in community care coordination. The study's use of Community-Based Participatory Research and other scientific-based approaches to measure development is a major contribution to the field of care coordination and assessed, to some extent, the usefulness of the measures in helping to inform local quality improvement activities. Most of the measures were implemented as survey instruments rather than as measured directly from operational data as done here. The most relevant non-survey metrics related to Developing and Maintaining a Care Coordination Plan, Health Care Referral Scheduling, and Health Care Referral Completion. There were insufficient pilot test data to report on the care coordination measure. (For the care coordination plan, few records were found complying with these activities, and sites that reported care plans under development did not actively document this task—a requirement per measure specifications.)

Results are presented for timeliness of referral scheduling and completion. More than 40 percent of referrals (40.8%, n = 1, 157) were completed within 14 days and nearly two- thirds were completed within 30 days (Figure 3). Most of these completed referrals were for primary care visits. The completion rates were lower for mental and behavioral health services as well as other types of specialty care. Of the 101 clients who did not complete their referral, more than half (58.4%) did not appear for a scheduled appointment. This measure highlighted a documentation challenge for some of the sites. The measure specification requires confirmation from the health care provider to demonstrate the completion of the referral. Yet in practice, some sites relied on client confirmation."

Our results are consistent with these findings showing that adherence is a problem with even a lower adherence rate. However more significantly from a methodological standpoint, we provide a formalized approach to obtaining adherence values from primary Pathway data with well-defined consistency filtering. This enables adherence measurement to become a standardized feature of care coordination based on Pathways and supported by computerized implementation such as the active calendar.

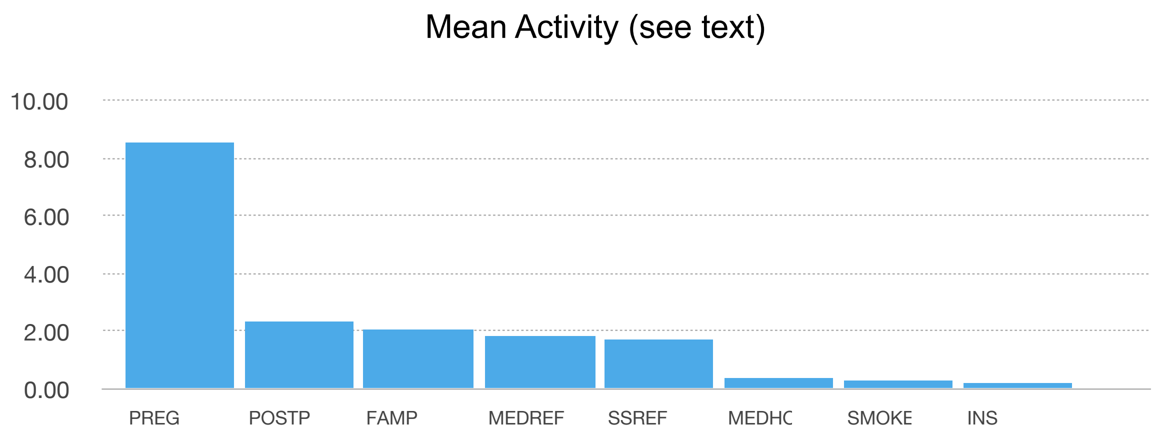
Outcome Metrics Based on Formalization

The completeness metric developed for the Pregnancy Pathway illustrates the need for filtering client records to eliminate certain end states where appropriate. The tools developed enable outcome analysis of subsets of clients subject to the filtering criteria just discussed and further constrained by various attributes available on client profiles in the data. Such analytics and the results of application to CHAP data are described in Appendix E. These results lead to the conclusion that the percentage of normal births at the output of the Pregnancy intervention process appears to be more appropriate than the percentage of low weight births as an effectiveness measure. The normal births percentage takes account of both low weight births and undocumented cases and clients that left before completion of care. Using this approach, we examined how outcomes vary in client subsets such as those based on race and age, as well as from external sources such as referrals and payer contracts. We found that the use of metrics of community health worker (CHW) and client performance such as activity, consistency, and adherence seem to verify anecdotal observations that different client streams receive differing levels of quality of care. The local minority care coordinators are able to reach out to African American women and engage them quickly into the program. This contrasts with the administrative delays that reduce that time available for managed care clients to receive proper intervention. This tends to corroborate our conjecture that different risk policies and client processing times of such sources can negatively influence pregnancy outcomes.

Pathway Activity Distribution

According to our data, about half of the pathways constituted most of those employed in practice in the years 2009–13. The total activity of a pathway is computed as the total number of events recorded for that pathway's overall clients during the period of interest. The mean activity is the total activity divided by the number of clients in that period. As shown in the chart of Figure 8, the pregnancy pathway is by far the most active (as is to be expected) while of the four other pathways the most active are postpartum, family planning, medical referral, and social service referral. These and other results shown in this paper are based on the actual set of clients (N = 262) resident in the database from 2009–13.

Figure 8. Pathway activities ordered from largest to smallest

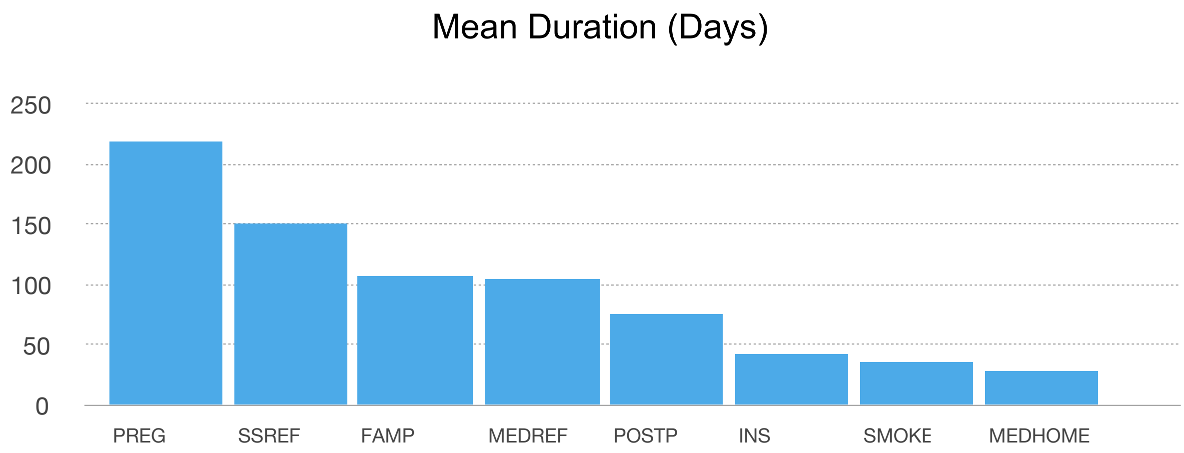


Pathway activity can be correlated to personnel and resource expenditures to calculate costs using time-driven activity-based costing [22]. Distributions of activity such as in Figure 8 (based on our analysis of CHAP data) can be used to inform quality improvement planning.

Pathway Duration Distribution

Another measure that is computable is the duration of a pathway instance; this is the difference between the dates of the initiating step and the completion step (either successful or not) or the closure step. Figure 9 orders pathways according to the mean durations of pathways (pathway durations averaged over clients participating in pathway). Note that the durations of the Pregnancy pathway relate to the length of pregnancies but include the effect of the pregnancy stage at which the client enrolled. Deeper analysis of the activity and duration data probes the dependence on client profile and can yield insights into the program operation (see Ref [21]). The longest duration pathways in Figure 8 are the same high activity pathways in Figure 9, the order in which they placed reflects the natural processes (e.g., the Postpartum pathway is very active as it is required of all clients), but the required appointments take only a month or two to accomplish.

Figure 9. Pathway durations ordered from largest to smallest



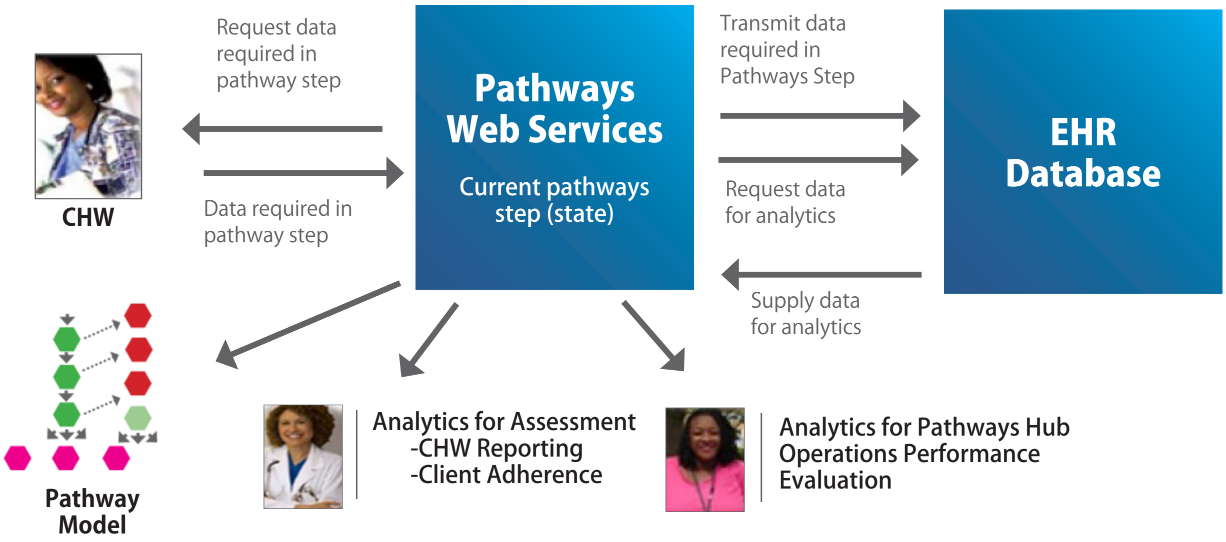
Temporal Metrics

As is clear from the formalization given above, the Pathway Model associates dates with pathway steps. Therefore it enables metrics, such as the Pregnancy Pathway duration, to be defined based on differences between dates. Metrics involving time difference between successive dates can answer questions about how long it takes for clients to make and keep appointments, or viewed from the supply side, how long it takes to deliver services of various kinds. Alternatively, dividing the number of successive events within a time interval by the length of the interval gives rates of event occurrence. Rate-limiting steps, mentioned in the Section "Pathways Concept" can be identified by criteria which set thresholds below which rates are considered to be too low. Warnings and alerts can be generated automatically based on the active calendar implementation of the Pathway Model. More in-depth analysis of time-indexed events can reveal more in-depth understanding of Pathway processes. For example, the number of different pathway types that are concurrent for a client can be computed by observing multiple pathway time series during the same period.

Supporting the HUB Data Infrastructure: A Vision for the Future

As shown in Table 1, the Pathway Community HUB Certification requirements specify that the Care Coordination Agency's data infrastructure is allowed to employ either paper-based manual or automated tracking to report on the metrics such as the number and type of clients in total and per care coordinator, Pathways completed by type, for agency, per care coordinator, and per client, and Pathway states. More inclusively, the Pathways formalization just presented can serve as the basis for advanced IT support of the data infrastructure. Such formalization affords a solid, implementation-independent basis for enhanced computerized support for algorithms that provide coordination of care based on the Pathways concept. Figure 10 depicts an approach to implementing the pathways formalization with a Web-Based Pathways Simulator (WPS) based on DEVS theory [23].

Figure 10. Formalization-based pathways implementation



The Web-Based Pathways Simulator mediates between the EHR database holding client data and users of data. Such users include CHWs, care providers, managers, quality improvement analysts, etc. At the first level, the WPS guides CHWs in entry of data according to the dictates of the DEVS Pathway Model currently in focus. The WPS does this, knowing the state of the Pathway Model and therefore, the current step of the pathway. The WPS is built on top of a DEVS Simulator operating in real-time mode so that scheduled events occur anchored by a Calendar class that properly manages time in terms of current wall-clock seconds, hours, days, and years. The DEVS Simulator handles the time management, event scheduling, state transitions, and input/output of the DEVS Pathway Models. Multiple model instances may be active at any time to represent several concurrent pathways of a single client as well multiple such instances of the current set of clients with records resident in the database. Other functions that are based on the formalization include analytics for client assessment (i.e., adherence//compliance, see Section on Client Adherence Analysis) and for HUB operation (Reporting Quality, Outcome Evaluation). These are of interest to care coordinators (CHWs, supervisors) and operations analysts, respectively.

Conclusions

The emerging national IT infrastructure will not provide significantly greater coordination of care since it does not provide transparency into the threads of transactions that represent patient treatments, their outcomes, and total costs. Such transparency is afforded by the Pathways Model which enforces threaded distributed tracking of individual patients experiencing certain pathways of intervention, thereby supporting coordination of care and fee-for-performance based on end-to-end outcomes. We have reviewed the Pathways Model and provide a formalization of pathways that serves as a basis for quality improvements in coordination of care involving computerized support for better pathway reporting, improved client adherence to their recommended activities, and improved coordination among the payers and agencies involved. Recently developed Standards for Pathways Community HUB Certification include a requirement for compliance to standard Pathway specifications, although such specifications are not included in the current draft. The formalization proposed here can provide a firm basis for such specifications. More generally, the formalization provides a well-defined means for a uniform description of such basic Pathways as well as for new Pathways as they are introduced in practice. Formalization also enables automated checking for duplication and overlap of Pathways and agencies desiring to service a Pathway for a client. We showed how, based on the formalization, system-level performance metrics can be defined to be monitored and used to inform the HUB certification-required quality improvement planning, Care coordination milestones are explicitly included in the end states of the formal models we defined which, via tracking and monitoring, link payments to accomplishments.

The Pathways Community HUB model provides a framework to coordinate and track the care activities of individual patients toward positive outcomes in order to improve health care quality and to facilitate cost reducing outcome-based payment strategies. Formalization of the Pathways Model will enable it to become a widely applicable framework for care coordination. This will significantly contribute to the overarching goal of developing a predictive modeling methodology to support re-engineering the health care system of systems. In turn, this will have a broad impact for health care whereby the patients at highest risk with greatest burden on the nation's health system can be moved toward optimal self- management to improve the quality of their care and significantly reduce its cost. Moreover the modeling methodology will reliably predict the quality versus cost performance for such coordinated care. This would provide a basis for negotiations on proposed coordinated care proposals between Center for Medicare and Medicaid Services and the Accountable Care Organizations that are the essential vehicles for cost reduction in the Affordable Care Act.

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Appendix A: Clinical Pathways

Generally speaking, clinical care pathways (CP) consist of algorithms (usually informally presented as a flow chart with conditional branching) that delineate the overall structure of decisionmaking for treating a specific medical condition. CPs are referenced in the literature under a variety of names such as clinical pathways, critical pathways, and clinical process models, and there is no single, widely accepted definition, although key characteristics have been extracted from over 200 articles [1]. Since the introduction in the 1990s, CPs have become widespread in hospital health care management [2]. A comprehensive analysis of 27 published studies compared outcomes and costs for hospitals that used clinical pathways with those that do not. It found CP use was correlated with benefits in reduction of in-hospital complications, decreased length of stay, and reduction in hospital costs [3]. A recent large scale study for knee surgery found reduction in length of stay and avoidance of treatment complications for hospitals using CPs versus non-users [4].

Based on the concept analysis of Ref. [1], the European Pathway Association derived an all-inclusive definition of care pathways [5]:

"A care pathway is a complex intervention for the mutual decision making and organization of care processes for a well-defined group of patients during a well-defined period.

Defining characteristics of care pathways include:

- An explicit statement of the goals and key elements of care based on evidence, best practice, and patients' expectations and their characteristics;
- The facilitation of the communication among the team members and with patients and families;
- The coordination of the care process by coordinating the roles and sequencing the activities of the multidisciplinary care team, patients and their relatives;
- The documentation, monitoring, and evaluation of variances and outcomes; and
- The identification of the appropriate resources."

"The aim of a care pathway is to enhance the quality of care across the continuum by improving risk-adjusted patient outcomes, promoting patient safety, increasing patient satisfaction, and optimizing the use of resources" [6].

Not all studies indicate successful application of CPs. Ref. [3] noted that although use of pathways tended to improve documentation; nevertheless, poor reporting prevented the identification of characteristics common to application of successful pathways. Shi et al. [7] enumerate eight types of factors that can influence results. They consider factors in CP design, execution, and evaluation (CP design: inclusion of all participating disciplines, applicability to intended medical condition, flexibility incorporated in pathway specification; CP execution: training of participants, continuous improvement, psychological influences, computer-support; and CP evaluation: consideration of multiple factors).

Care pathways, originally described in paper form, are being implemented in computerized form in which they can support a variety of functions [8].

Modeling, Simulation, and Operationalization of Clinical Pathways

Recent interest in computerization of clinical pathways has stimulated considerable work in treatment of pathways from computer science and software engineering perspectives. Here we provide a framework for organizing the literature that has emerged to help understand the nature of the variegated contributions.

We consider a clinical pathway as a mathematical system model that is being designed and manipulated to support re-engineering an existing real-world clinical process. This allows taking a systems engineering approach in which the system is modeled and simulated before being implemented in reality (i.e., operationalized in a hospital environment). Generally this approach takes the following phases [e]:

1. Determine objectives. Clarify requirements (specify the decisions that model should support), values (how to measure the model outputs), and weights (how to weight the measures).
2. Gather relevant data. Find the right data and validate it to make sure it is representative of the system.
3. Construct model. Choose a model formalism to express it, infer its structure and/or calibrate it with data gathered in the previous step, and validate the model against unused data or newly gathered relevant data.
4. Simulate model. Formulate alternative decisions and run simulation experiments to get the model's evaluation of these alternatives.
5. Implement model. Select highly ranked alternative and re-engineer current pathway implementation to operationalize the model.

Table A-1 organizes some of the aspects subject to modeling and simulation in terms of these phases.

Table A-1. Phases of modeling and simulation of clinical care pathways (CPs)

Phase	Sub-aspects and references in literature
Determine objectives:	Pathway personalization to provide care plans, 15, Pathway customization, 21 Support consensus formation, 17 Care standardization, 30 Identify process bottlenecks, 31
Gather relevant data:	Process and time dependency mining, 10,23,27 Variation monitoring, 19 Use clustering and multidimensional scaling, 28 Use Similarity-Based patient traces, 30 Observe individual patient treatment and waiting times, 31
Phase	Sub-aspects and references in literature
Construct model:	Learn Patterns for Markov Model, 11 Model based on Ontology, 13,16, 29, extended to incorporate patient state, intervention and time, 25 Semantic-based workflow model, 14 Normative Semiotics Model, 15 Witness Software, 31
Simulate model	Verify and validate behavior, 17 Observe critical activities and scarce resources, 31
Implement model	Operationalize Pathway, 18 Manage workflow, 14, 18, 22 Manage CP variance, 18, 20 Intelligently reconfigure, 19 Evaluate patient satisfaction, 24

Some of the aspects of pathway formalization are exploited in a generic architecture for execution of CPs capable of adapting to individual patient variations [32]. Its holistic IT solution comprises an inference engine (operating on a CP-based rule set) assisted by a semantic infrastructure (based on existing disease and business ontologies) supporting adaptation and reconfiguration during the execution.

Comparing HUB Coordinated Care and Clinical Pathways

Many of the features discussed above are common to both coordinated care and clinical pathways. However, coordinated care pathways are focused on accomplishment of steps, with associated accountability and payment schemes. Consequently, they specify tests for accomplishment and time bounds within which such tests much be satisfied. While clinical pathways are procedure oriented (i.e., tend towards increased granularity in prescribing clinical processes), care coordination pathways are more declarative (i.e., tend toward specification of goals and sub-goals rather than procedures for achieving them.) Care coordination pathways are like skeletons showing paths and benchmarks while clinical pathways are full-bodied handbooks of action.

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Appendix B: Data Challenges and Remedies

As indicated in the main text, the Community Health Access Project (CHAP) agreed to provide access, under suitable data sharing agreements, to its database of client and pathway records. We collected de-identified personal health and behavioral data (such as demographic, socio-economic, etc.) for successfully and unsuccessfully treated clients from the electronic health record (EHR) database employed by CHAP. The study was a retrospective review of a data set captured in NetSmart's EHR between 2009 and early 2013. Community health workers (CHWs) captured client visit information on paper forms and then transcribed data into the electronic health records upon return to the office. The EHR data was stored in a relational database, and each client was assigned a unique identification number (ID), serving as a primary key within table rows to associate data elements to specific clients. The data fields capture responses to initial interview questions as well as notes entered by CHWs after each home visit.

The system did not provide sufficient means to analyze its data. In order to enable such analysis, as well as to create an independent de-identified data set, we developed an approach to export data tables into spreadsheet forms. Furthermore, to explore the data, we developed an array of tools to join client record rows from various data tables and to "slice and dice" the data for the various analyses discussed in this report

Data Challenges

As mentioned in the main text, as with previous studies of Pathways coordinated care, we encountered problems with the quality of the data extracted from the CHAP database. Data validity refers to the level of completeness (i.e., the amount of missing data for a data element), accuracy (i.e., the extent to which the data reflects the underlying state or process of interest), and granularity (i.e., clinical specificity). Valid data captured from EHRs and other health IT tools allow for accurate summary and measurement of care processes and patient outcomes. However, ensuring the validity of EHR data has been noted to be a significant challenge [1,2]. To illuminate such challenges in the particular context of Pathways-based coordinated care, we identified the following problems in the data entered by community health workers in the CHAP database:

Absence of database information:

- Lack of metadata describing the data set;
- Absence of an entity relational diagram describing the database structure;
- Lack of data collection policy or procedures to guide the data entry process; and
- Limited data quality processes to ensure data integrity and accuracy.

Missing database features:

- Lack of report writer;
- Non-normalized data table structure;
- Inconsistent naming convention of database table primary keys (i.e., client ID vs. patient ID);
- Lack of data validation rules to support consistent data entry; and
- Nonexistent database taxonomy.

Data entry issues:

- Inability to clearly identify episodes of care—we conjectured that some clients were followed by the CHW for at least two pregnancies based on the date range of visits;
- Text data entry fields allowed multiple data representation of identical concepts such as High Blood Pressure vs. Hypertension;
- Text data entry fields did not provide support for human entry errors such as Anemia vs. Amenia;
- Text data entry allowed a wide array of noncomparable data values such as fraction vs. decimal measures;
- Data entry fields accepted more than one variable per data cell confounding data aggregation attempts: here is an example of preginit_cond_other field entry where two medical conditions are combined: "Asthma Client also has seizures but has not had a seizure in over a year";
- Absence of key data elements that our research hoped to find such as the inability to determine the specificity of a particular social reference type; and
- Incomplete data fields.

As with other researchers, the issue becomes the ability to determine a close approximate of the relevant data element. It would be helpful to have another data source that provided clinical data confirmation of the client self-reported infant birth weight. Our extraction of data for analysis revealed a number of limitations in the current implementation as noted above. A significant challenge for the research was that data collection was incomplete; our findings suggest that some data fields were never completed. There was a higher instance of data field completion of those data elements that were associated with service payments. Data entry was not standardized. Most data fields did not have any prescribed data validation filters. The result was a wide array of noncomparable data values. Issues included mixed units of measures (lb., kg, oz.), fraction values, and decimal values (5.5 lbs., 6 ¾ lbs.) This common issue is that data elements are often entered inconsistently in multiple locations or in different formats within the same EHR or across EHR systems. For example, smoking status may be entered numerically (e.g., cigarettes per day), in a structured format (e.g., check box indicating "tobacco user"), or an unstructured field (i.e., free text) [2]. Calculating quality measures using incomplete, inaccurate, or inconsistent data can lead to miscalculated denominators (e.g., patients eligible for a measure) and numerators (e.g., those eligible who received recommended care), and reduce the overall validity of the measure results.

Suggested Remedies

Approaches to overcome the challenges in use of EHR data as encountered in the present study are suggested in the following table:

Table B-1. Overcoming the challenges in use of EHR data

Issue	Remedy
Absence of database information	Provide necessary information on database structure
Lack of metadata describing the data set	Provide metadata drawing upon available ontologies
Absence of an entity relational diagram describing the database structure Lack of data collection policy or procedures to guide the data entry process	Provide guidelines for data collection and entry with incentivized enforcement and computerized support to ease adherence to these guidelines
Limited data quality processes to ensure data integrity and accuracy Missing database features Lack of report writer Non-normalized data table structure Inconsistent naming convention of database table primary keys (i.e. client ID vs. patient ID) Lack of data validation rules to support consistent data entry Nonexistence database taxonomy	Provide processes to ensure data integrity and accuracy Provide necessary database system features Provide report generator and analysis tools Normalize data table structure Enforce consistent naming conventions
Data entry issues Inability to clearly identify episodes of care Text data entry fields allowed multiple data representation of identical concepts.	Provide data validation rules to support consistent data entry Provide database taxonomy (ontology) drawing upon available ontologies (also support metadata mentioned above)
Text data entry fields did not provide support for human entry errors Text data entry allowed a wide array of noncomparable data values	Include fields to encode different episodes Enforce unique representations of concepts (employing available ontologies) or provide standardized cross-mappings if multiple representations are allowed Provide validation that rejects invalid entries
Data entry fields accepted more than one variable per data cell	Enforce unique representations of data values (employing available ontologies) or provide standardized cross-mappings if multiple representations are allowed Define fields that accept only one variable or provide tools that can semantically analyze unstructured entries Design data schema to include key elements that are required for analysis
Absence of key data elements that our research hoped to find, such as the inability to determine the specificity of a particular social reference type. Incomplete data fields	Provide support to ensure (encourage) complete entry of fields

Caveats

The data quality issues raised here can be seen within a broader context of problems that have arisen with electronic health record systems as they become more widespread and required for use under federal health care policies. Koppel [3] recently called the universe of electronic health record systems a "Tower of Babel" noting that few physicians could meet meaningful use criteria [4]. Many physicians were doubtful about the effects of EHR use on the quality, costs, or efficiency of health care in the United States. This Tower of Babel situation is partly due to the lack of adoption of a single standard for EHRs. Continuity of Care Record (CCR) is a health record standard that uses eXtensible Markup Language (XML) to provide flexibility that will allow users to formulate, transfer, and view such records in a number of ways, such as in a Health Level 7 (HL7) message, the most widely adopted health IT message standard [5].

In this context, the remedies suggested above can be viewed as providing approaches to particular problems within larger problem sets. The need for standardized data schema in health IT can be viewed within the general limitations of HL7 which does not include elements that relate to coordinating care services under consideration here. The suggestions above to base standardization on ontologies have to recognize that current ontologies for health care, notably NIH's Unified Medical Language System [6], are focused on medical terminology and do not address coordination of care. Currently there are efforts to develop standards for exchange of EHR data and for improving the interfaces that enable health care users to better visualize the data and to explore and query data sets of interest to them [7].

Most relevant to this report is the development of support for data entry that encourages accurate and complete entry of pathway events by CHWs as they occur in interacting with the client. The formalization and associated proposed implementation of the Pathways Model address these limitations with the intention of providing a design for an improved implementation. The lack of ontologies for coordination of care also motivate criteria for the proposed formalization to lay the basis for standards for Pathways semantics and pragmatics that eventually can be incorporated into EHRs [8].

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Appendix C: Pathways and Steps

Table C-1. Pathways and Steps

Pathway name	Pathway service code	Pathway step definition
Behavioral Referral Pathway	BEH1	Behavioral Referral initiation date
	BEH2	Scheduled behavioral eval. appointment date
	BEH3	Completed – appointment kept
	BEH4	Behavioral Referral PW finished incomplete
Developmental Referral Pathway	DEVR1	Developmental Referral initiation date
	DEVR2	Scheduled evaluation date
	DEVR3	Completed – date of develop. evaluation
	DEVR4	Develop. Referral PW finished incomplete
Developmental Screening Pathway	DEVS1	Developmental Screening initiation date
	DEVS2	Completed – no concerns
	DEVS3	Completed – concerns identified
	DEVS4	Develop. Screening PW finished incomplete
Family Planning Pathway	FAMP1	Family Planning initiation date
	FAMP2	Family Planning scheduled appointment date
	FAMP3	Family Planning appointment kept
	FAMP4	Family Planning missed appointment date
	FAMP5	Completion – still using method after 30 days
	FAMP6	Family Planning Pathway finished incomplete
Immunization Referral Pathway	IMMR1	Immunization Referral initiation date
	IMMR2	Immz. Referral scheduled appointment date
	IMMR3	Completed – immunizations up-to-date
	IMMR4	Immz. Referral Pathway finished incomplete
Immunization Screening Pathway	IMMS1	Immunization Screening initiation date
	IMMS2	Completed – immunizations up-to-date
	IMMS3	Completed – immz. are not up-to-date
	IMMS4	Immz. Screening Pathway finished incomplete
Health Insurance Pathway	INS1	Health Insurance initiation date
	INS2	Date application sent
	INS3	Completed – Health Insurance received
	INS4	Completed – Health Insurance denied
	INS5	Health Insurance Pathway finished incomplete

Pathway name	Pathway service code	Pathway step definition
Lead Pathway	LEAD1	Lead initiation date
	LEAD2	Scheduled appointment date
	LEAD3	Completed – normal results
	LEAD4	Completed – abnormal result
	LEAD5	Lead Pathway finished incomplete
Medication Management Pathway	MANAGE1	Medication Management initiation date
	MANAGE2	Date Medication Chart sent to provider
	MANAGE3	Appoint. kept with provider to review meds
	MANAGE4	Completed – Chart reviewed and no concerns
	MANAGE5	Med Management PW finished incomplete
Medication Assessment Pathway	MED1	Medication Assessment initiation date
	MED2	Date Medication Chart sent to provider
	MED3	Completed – Chart reviewed and concerns
	MED4	Completed – Chart reviewed and no concerns
	MED5	Med Assessment Pathway finished incomplete
Medical Referral Pathway	MEDREF1	Medical Referral initiation date
	MEDREF2	Medical Referral scheduled appointment date
	MEDREF3	Medical Referral appointment kept
	MEDREF4	Medical Referral
Postpartum Pathway	POSTP1	Postpartum initiation date
	POSTP2	Postpartum appointment scheduled date
	POSTP3	Postpartum appointment kept
	POSTP4	Postpartum Pathway finished incomplete
Pregnancy Pathway	PREG1	Pregnancy initiation date
	PREG2	First prenatal appointment date
	PREG3	Kept prenatal appointment date
	PREG4	Delivery date ≥ 2500 grams
	PREG5	Delivery date < 2500 grams
	PREG6	Pregnancy Pathway finished incomplete
Smoking Cessation Pathway	SMOKE1	Smoking Cessation initiation date
	SMOKE2	Completion - client self-report
	SMOKE3	Completion - lab test confirmed
	SMOKE4	Smoking Cess. Pathway finished incomplete
Social Service Referral Pathway	SSREF1	Social Service Referral initiation date
	SSREF2	SS Referral scheduled appointment date
	SSREF3	Social Service Referral appointment kept
	SSREF4	SS Referral Pathway finished incomplete

Appendix D: DEVS Background

Since its introduction in "Theory of Modeling and Simulation," 1976 [see ref 1 below], the Discrete Event System Specification (DEVS) formalism has spawned an approach to modeling and simulation that has taken root in academia and is emerging into common research and industrial use.

A DEVS model is defined as a mathematical and logical object which serves as a way of specifying a dynamic system as defined in ref. 2 below.

The following briefly summarize the elements of a DEVS model:

States

A state can either be a "hold state" or a "passive state." A hold state is one that the model will stay in for a certain amount of time before automatically changing to another state (via an internal transition). A passive state is one that the model will remain in indefinitely (or until it receives a message that triggers an external transition).

Time Advance

Every state has a time advance value which specifies the amount of time that expires before it automatically changes to another state (via an internal transition). The time advance for a "hold" state is a finite real value. The time advance for a "passive" state is infinity.

Initial States

One state in the model must be designated as the initial state from which all interaction with the external word commences.

Internal Transitions

Every hold state in the model has one internal transition defined in order to specify the state to which the model should transition after the specified amount of time.

Output

Any state that has an internal transition can also have one output message that is generated before that internal transition occurs.

External Transitions

Any state can have one or more external transitions defined. An external transition defines an input message that the model might receive when in a given state and the state to which the model should transition in reaction to that input message.

Background on DEVS is available in the following books:

References for Appendix D

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Appendix E: Analysis of Outcomes of Client Sources and Other Subsets

The draft study of Community Health Access Project (CHAP) effectiveness [10] employed reduction in risk of low birth weight (LBW) as the relevant effectiveness measure. Although we start with this approach to outcome measurement, we will come to the conclusion that the percentage of normal births at the output of the process may be more appropriate. Indeed, if there are undocumented or untreated clients, then low birth weight and normal births are not necessarily inversely related, in which case the percentage of normal births is the most informative metric. We then examine how outcomes vary in client subsets such as those based on race and age, as well as from external sources such as referrals and payer contracts. We will use metrics of community health worker (CHW) and client performance defined earlier, such as activity, consistency, and adherence, to throw light on how these outcomes vary across subsets. Based on actual experience with CHAP, we conjecture that different risk policies and client processing times of such sources can influence the types of clients and the stages of pregnancy at which they are enrolled. These factors, in turn, can influence the pregnancy outcomes.

Measuring Outcomes

For any subset of clients, S, we define the number of Low Birth Weight: outcomes as LBW = #PREG5, the number of clients assigned a PREG5 (i.e., delivered a LBW baby).

From these raw data, we compute the Low Birth Weight percentage:

%LBW = 100*LBW/#S

where #S is the number of clients in the subset, S. The size and percentage LBW of various subsets is shown in Table E-1.

Table E-1. Size and percent low birth weight by racial and age groups

Client subset	Size	Percent low birth weight
Overall	259	7.0
African American	91	10.8
White/Non-Hispanic	153	5.2
Age 18 and younger	37	0
Age 18–25	121	9.2
Age 25–30	68	5.0
Age 30 and older	43	7.8

While the overall LBW rate is approximately 7 percent, it is not uniform across race and age sub-sets. African

Americans have twice the LBW rate (nearly 11%) as Whites while the 18–25 age group has the highest LBW (approximately 9%) of the other age categories. To be meaningful in assessing effectiveness, these rates must be compared against baseline values that characterize the populations from which these clients are drawn. Unfortunately, the data does not contain a control group representing such populations. (In contrast to the prior study [10], we will not recreate a comparable data set from census data.) For a rough comparison, it is generally accepted that risk of low birth weight infants for African Americans in the population served by CHAP is approximately 14 percent with Whites again at half this risk. Thus, the effectiveness of the Pathways intervention for this data set appears to be to reduce the risk for African Americans from 14 percent to 11 percent with corresponding reduction for Whites.

To gain more insight, we compared the LBW rates of different sources of clients (such as referral programs, Medicaid contracts, as will be discussed) for insight into what factors may be influencing the observed variations. This examination leads to the realization that LBW rate may not be the only or best measure of effectiveness. Consider the following definitions:

Normal = #PREG4, the number of clients assigned a PREG4 (i.e., completed normal birth)

%Normal = 100*Normal/#S

and

Remaining = #S – (Normal + LBW)

%Remaining = 100 – (%Normal+%LBW)

That is, the last category includes all those not accounted for by the PREG4 and PREG5 labels, which includes those officially documented as incomplete (PREG6) and any others not so documented. Table E-2 shows the percent LBW, percent Normal. and percent Remaining for various client subsets.

Table E-2. Outcomes for racial and age groups

Subset	%LBW	%Normal	%Remaining
Overall	7.0	75.2	17.8
African American	10.8	79.3	10.8
White/Non-Hispanic	5.2	76.6	18.2
Age 18 and younger	0	20	80
Age 18–25	9.2	75.8	15.0
Age 25–30	5.0	85.0	10.0
Age 30 and older	7.8	74.5	17.6

Notice that a considerable number of cases overall, close to 18 percent, are in the “Remaining” column and this number varies considerably in the categories. This suggests that the Normal and LBW fractions are not always inversely correlated as they would be if all clients were always accounted for. Indeed, we see that the Age 25–30 category has the highest percent Normal (85%) but those under 18 have the lowest percent LBW (0%). In the racial breakdown, as we saw before, African Americans have a higher percent LBW than do Whites, but we see now that they also have a higher percent Normal (80%) due a smaller percent Remaining.

Payer Plans and Other Client Sources

Table E-3 shows characterization of payer plans and other client source streams found in the CHAP data set with de-identified names.

Table E-3. Characterization of client source streams

Properties of sources	Client Source A	Client Source B	Client source C	Client Source D
Medicare Managed Plan		x	x	
Disadvantaged Population Focus	x	x	x	x
Charity				x
Not for profit		x		
For profit			x	
Local	x			x
National		x	x	

The sizes of client source sets in the database and their outcome percentages are shown in Table E-4.

Table E-4. Size and outcome composition of client sources

	Client source size	% LBW	% Normal	% Remaining
Client Source A	73	11.0	82.0	8.0
Client source B	105	4.0	77.0	19.0
Client source C	27	15.0	70.0	18.0
Total of client sources	205	7	75	18

Client Source A has a relatively high percent LBW (11%). but also has the highest percent Normal (82%) due to its low percent Remaining (8%). These numbers correlate strongly with those of African Americans in Table E-2. Indeed, analysis of the composition of client source A shows it to serve only African American women. Table E-5 throws some light on these numbers by comparing previously defined metrics on client source A with all others. The table shows the average Social Service activity per client (number of Social Service Pathway steps) for client source A is approximately 4 whether for the LBW or Normal subsets. This compares with an average of less than 1 for others.

The consistency and adherence measures for the same Pathway are also shown in Table E-5. Again the numbers are much higher for client source A than for all others for both the LBW or Normal subsets. Recall that consistency is a measure of reporting competence for CHWs and adherence is a measure of client fulfillment of prescribed tasks. Thus it appears that CHWs have a greater impact in caring for client source A's clients than with others and that this shows up in much greater client adherence as well. These high performance levels on the part of client source A's CHWs and clients are consistent with the low percent Remaining under the interpretation that the latter is a measure of clients that leave the program due to "falling between the cracks." A key factor in the success of client source A clients is the way in which the program and referral into the program is set up. client source A is a community-based intervention, and CHWs find and engage their clients through canvassing, referrals from friends and family members, and provider referrals. The Medicaid managed care plans (MCPs) develop referrals based on claims data. A referral to CHAP for care coordination doesn't materialize until a claim is generated and a review process is initiated and concluded at the plan. CHWs must then go out and try to find the client in contrast to the warm hand-off in the client source A program.

Table E-5. Comparing client source A performance measures against all others

Client source		Avg activity per client in Social Service Pathway	Consistency %	Adherence %
client source A	LBW	4.38	63	58
	Normal	3.42	71	48
Others	LBW	<1	20	0
	Normal	<1	27	<1

Racial and Age Composition

The racial compositions of client sources appearing in Table E-6 shows that overall the clientele is split approximately 2:1 Whites to African American; however, client source compositions deviate significantly from the overall proportions.

Table E-6. Racial composition of client sources

Client source \Race	Size	African American %	White/Non-Hispanic %
client source A	73	100	0
Client source B	105	6	94
Client source C	27	16	84
Total of client sources	205	37	63

Age 25–30 is the most populated category with nearly half of the total while Age 18–25 has a quarter, and Age 30 and older a fifth of the total, the remaining clients occupying approximately 5 percent.

The chart in Figure E-1 shows that client sources are differentiated by their largest age category. This offers a partial explanation for the variation in the client source's LBW rate. Indeed, age composition correlates with the LBW rate of a client source in the sense that the latter reflects the relative magnitude of its predominant category. This is shown in the following Table E-7:

Figure E-1. Age composition of client sources

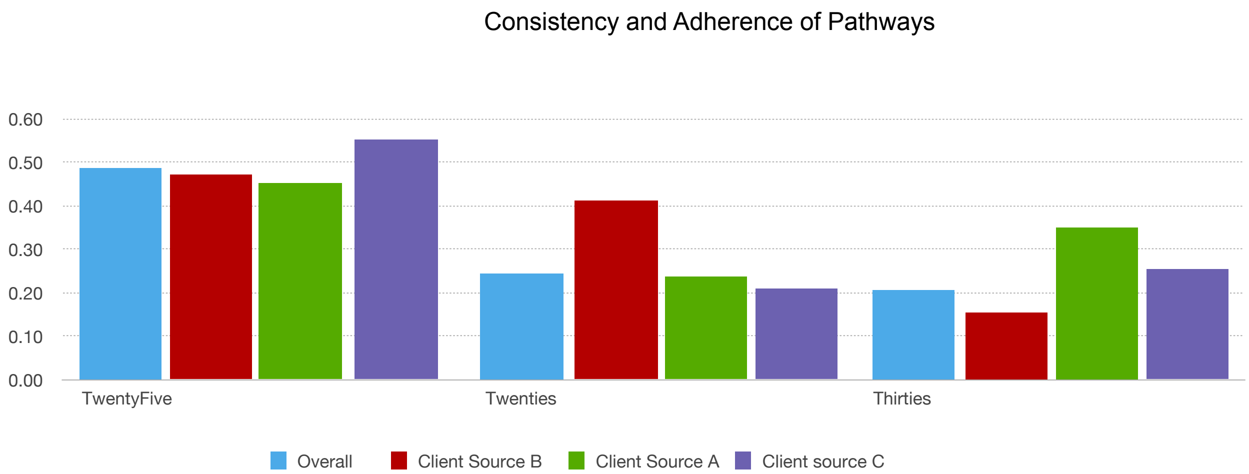


Table E-7. Correlation of predominant category and source's LBW rate

	Predominant Category in client source	Predominant Category's %LBW	Predominant Category's %LBW Relative rank	Client source's %LBW	Client source's %LBW Relative rank
Client source B	Age 25–30	5.0	1	4.0	1
client source A	Age 30 and older	7.8	2	11.0	2
Client source C	Age 18–25	9.2	3	15.0	3

The agreement in ranking gains some credibility in that it would be expected in the case that each client source is fully consumed by its predominant category, so that its statistics are inherited from its predominant category.

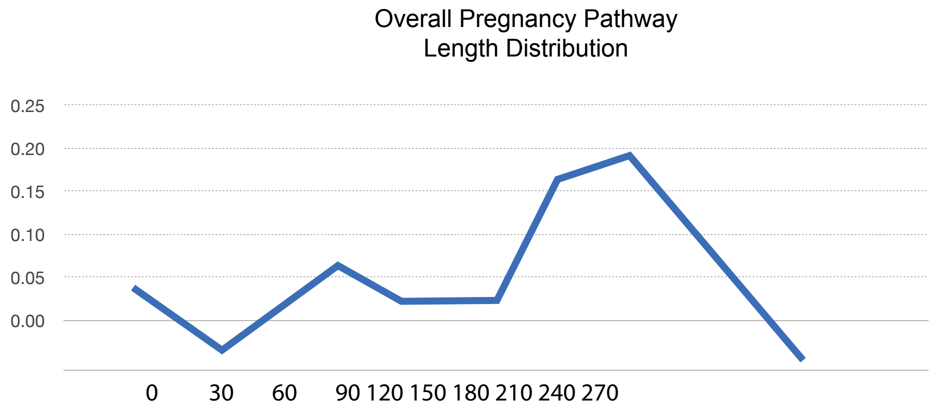
Pregnancy Pathway Length Distribution

The Pregnancy Pathway length for a client is the interval measured in days between the earlier of the initiation and first pre-natal appointment. Using the dates available from the Pregnancy steps in the CHAP database this length is obtained by subtracting the minimum of (PREG1 and PREG2 dates) from the PREG4, PREG5 or PREG6 date—whichever is recorded for the client. Recall that one and only one should be recorded for consistency and completeness. For any subset S of clients meeting these criteria, we obtain the distribution of lengths in a histogram with a bin size of 30 days.

The overall Pregnancy Pathway length distribution (for all clients meeting the condition) in Figure E 2 shows three peaks:

1. Peak at 0—possibly for those women enrolled late in third trimester and ready to give birth
2. Peak at 90 days—possibly for women enrolled in late in second trimester
3. Peak between 180 and 210 days—possibly for women enrolled in first trimester after 60 to 90 days when pregnancy has become apparent

Figure E-2. Overall Pregnancy Pathway length distribution



We examined this distribution for various subsets ranging over racial and age segments for correlations with outcome percentages. Figure E-3 shows the curve for the Age 25–30 group all with the distribution when this group is removed from the overall set. Note that this group has a higher peak at 210 days indicating that they had relatively more first trimester enrollees than others. This may partially explain this group's lower LBW rate on the basis that they could benefit from the longer period of care.

Figure E-4 shows the distribution for African American and White subpopulations. It clearly distinguishes the enrollment characteristics of these sets—the former showing the three distinct peaks while the latter showing a single peak at first trimester enrollment. As just discussed for the Age 25–30 group, this difference is consistent with a lower LBW rate for Whites.

Figure E-3. Pregnancy Pathway length distribution of Age 25–30 group vs all others

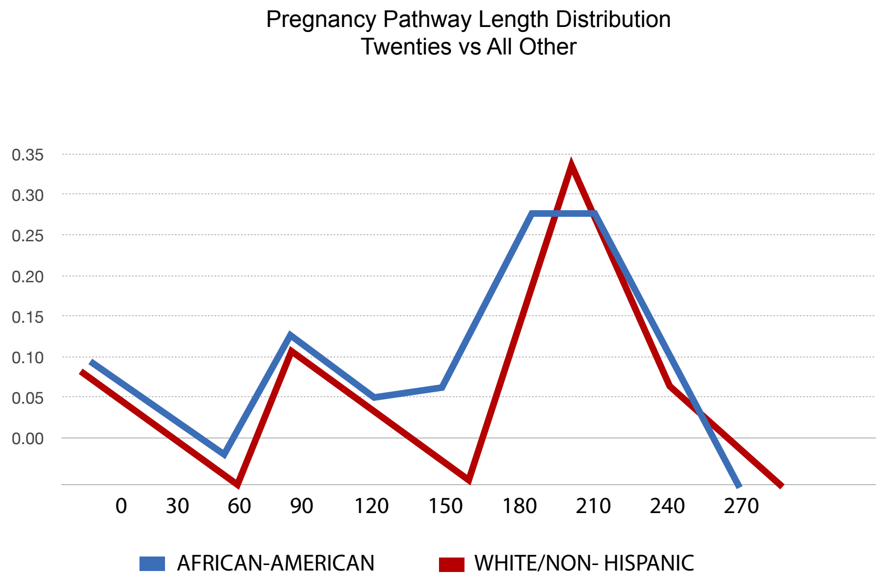
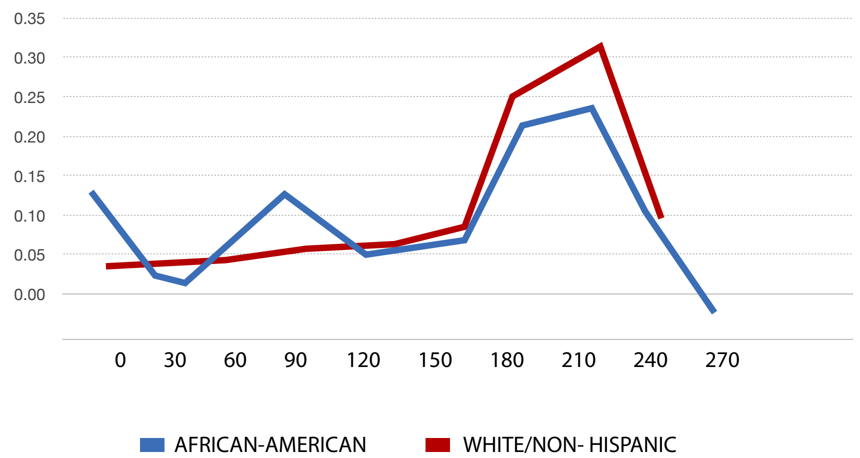
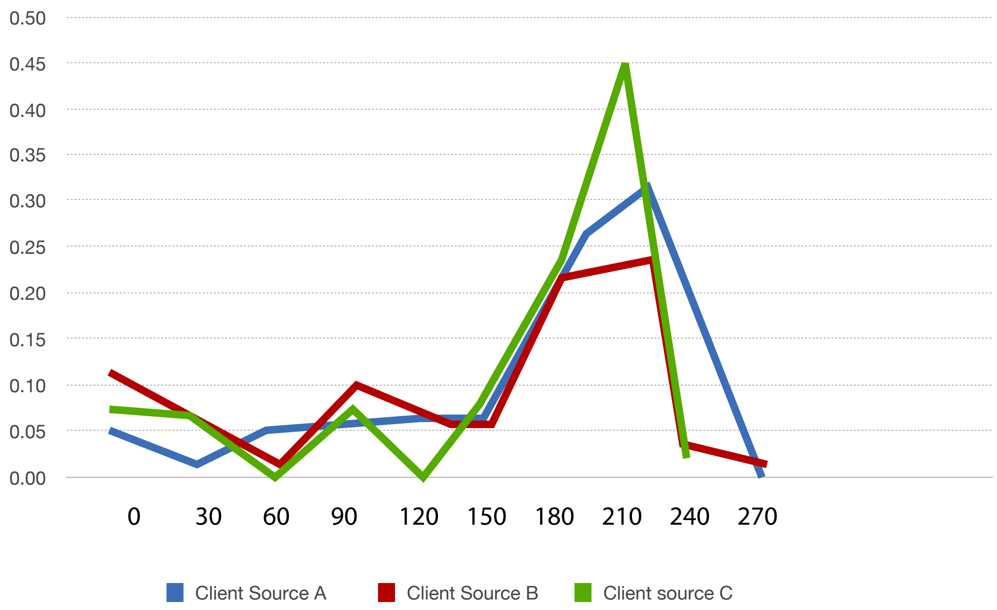


Figure E-4. Pregnancy Pathway length distribution for racial groups



The Pregnancy Pathway length distribution for the client sources in Figure E-5 shows that the curves for Client source B and client source A reflect those of their racial compositions just mentioned. However, the higher LBW rate for client source A should also be considered by recalling the earlier discussion of the effect on CHW and client in the Section on client source A outcomes.

Figure E-5. Pregnancy Pathway length distribution for client sources



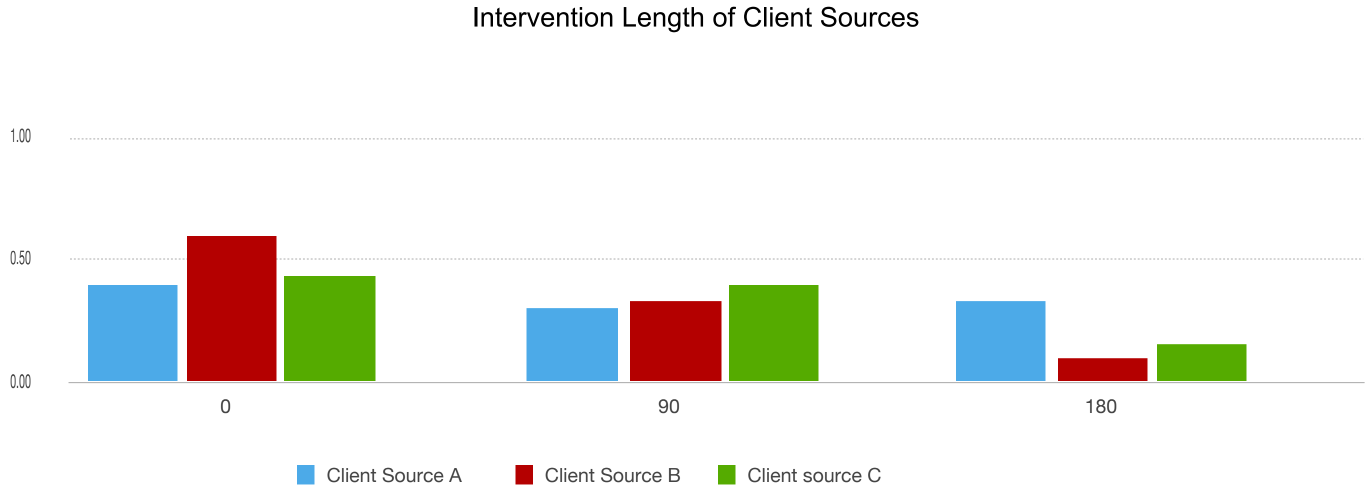
The Client source C curve is puzzling. It is distinguished by a very high peak at 210 days. To be consistent with the above discussion, this should be correlated with early enrollment and lower LBW rate. However, this rate is actually higher than the others. The high peak at 210 seems to contradict our conjecture that longer delay in processing for Client source C clients would show up in delayed enrollment shown by shifting of peaks to the left by the delay amount—say 30 to 60 days.

Intervention Length and Processing Time

The apparent contradiction led us to re-examine which definition of length of Pregnancy pathway to use. Recalling that PREG1 is the actual date of client enrollment suggests that we define the Intervention length as the length of the interval between the PREG1 and the PREG4, PREG5, or PREG6 date—whichever is recorded for the client. This distinguishes intervention length from the Pregnancy Pathway length discussed above. The latter is always longer and is a better lower bound on the actual length of pregnancy.

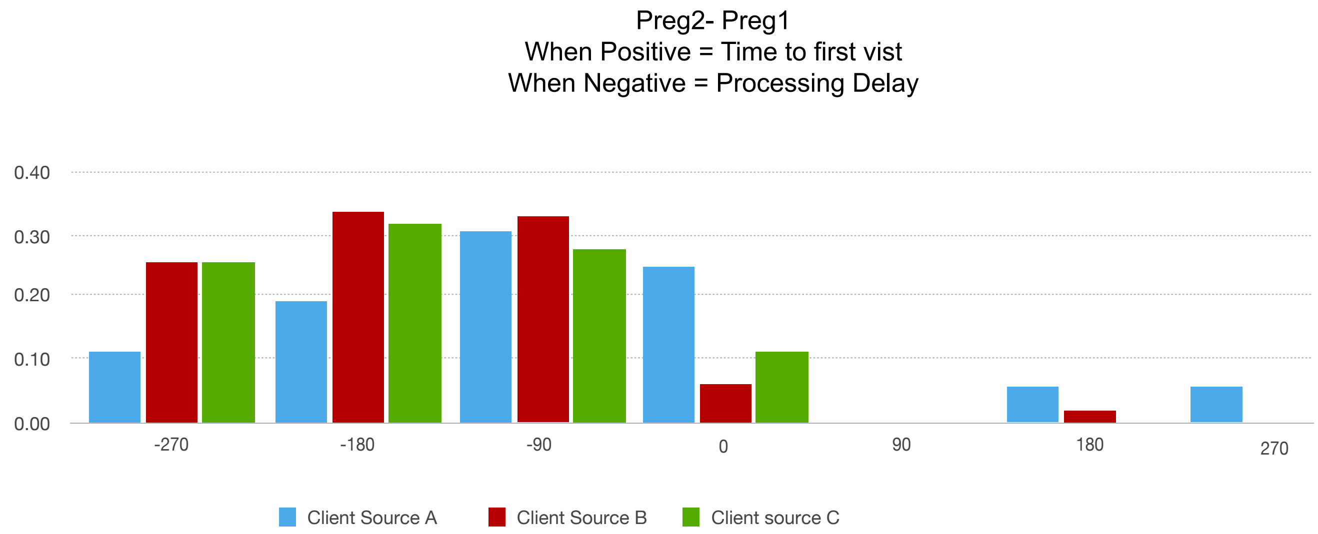
The intervention length distribution is plotted in Figure E-6 for bin sizes of size 90 days so that the bins contain lengths between 0 and 90, 90 and 180, and 180 to 270 labelled 0, 90, and 180, respectively. These bins correspond to enrollments in the 3rd, 2nd, and first trimesters, respectively. We see that the client source A distribution is more skewed toward longer intervention lengths while the Medicaid managed care plans (MCPs) are skewed toward the shorter lengths. This tends to corroborate the anecdotal observations that client source A clients are enrolled earlier in their pregnancies and therefore have more time to receive CHAP intervention services.

Figure E-6. Pregnancy Pathway Intervention length distribution for client sources



This conclusion is confirmed directly by looking at the pathway data in yet another way. Figure E-7 shows the distribution of the different PRE2-PREG1in bins of size 90 days. When PREG2 >= PREG1, the difference is positive and is the time it took for the client to make her first prenatal doctor visit after enrolling in CHAP; otherwise, PREG2 < PREG1, the difference is negative and represents the interval from the client's first doctor visit to her enrollment in CHAP. We will interpret this latter difference as representing a processing delay. Figure E-7 shows that the client source A distribution is significantly skewed toward positive values while the MCPs are skewed toward negative values, i.e., the latter have more processing delays than the former. Indeed, the largest concentration of the MCP distributions is located at -180 days, i.e., around 6 months of processing delay. This processing delay is anecdotally explained by the observation that a Medicaid managed care plan requires women to see an obstetrician to get a referral, which has to go through claims processing and risk scoring at the plan level. This administrative process causes delays in the women being admitted to CHAP, and so their pregnancy is further along, they receive less intervention, and they are harder to engage.

Figure E-7. Pregnancy Pathway PREG2-PREG1 distribution for client sources



Conclusions

The percentage of normal births at the output of the Pregnancy intervention process appears to be more appropriate than the percentage of low weight births as an effectiveness measure. It takes account of both low birth weights percentage and undocumented cases and clients that left before completion of care. Using this approach, we examined how outcomes vary in client subsets such as those based on race and age, as well as from external sources such as referrals and payer contracts. We found that metrics of CHW and client performance such as activity, consistency, and adherence seem to verify anecdotal observations that different client streams receive differing levels of quality of care. The positive differential between client source A and the MCPs in client adherence and normal birth outcome highlights the importance of keeping programs at the community level. For example, Richland County has received grants from client source A for the past decade. The county has hired local minority care coordinators to reach out to African American women and engage them quickly through canvassing the local Medicaid office, obstetrician offices, and community-based organizations. This contrasts with the administrative delays that reduce that time available for managed care clients to receive proper intervention. This tends to corroborate our conjecture that different risk policies and client processing times of such sources can negatively influence pregnancy outcomes.

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