Model Formulation ■

The AMPATH Nutritional Information System: Designing a Food Distribution Electronic Record System in Rural Kenya

Jason LitJeh Lim, MSIE, Yuehwern Yih, PhD, Catherine Gichunge, William M. Tierney, MD,
Tung H. Le, PhD, Jun Zhang, PhD, Mark A. Lawley, PhD, Tomeka J. Petersen, MSW,
Joseph J. Mamlin, MD

A b s t r a c t   **Objective:** The AMPATH program is a leading initiative in rural Kenya providing healthcare services to combat HIV. Malnutrition and food insecurity are common among AMPATH patients and the Nutritional Information System (NIS) was designed, with cross-functional collaboration between engineering and medical communities, as a comprehensive electronic system to record and assist in effective food distribution in a region with poor infrastructure.

Design: The NIS was designed modularly to support the urgent need of a system for the growing food distribution program. The system manages the ordering, storage, packing, shipping, and distribution of fresh produce from AMPATH farms and dry food supplements from the World Food Programme (WFP) and U.S. Agency for International Development (USAID) based on nutritionists' prescriptions for food supplements. Additionally, the system also records details of food distributed to support future studies.

Measurements: Patients fed weekly, patient visits per month.

Results: With inception of the NIS, the AMPATH food distribution program was able to support 30,000 persons fed weekly, up from 2,000 persons. Patient visits per month also saw a marked increase.

Conclusion: The NIS' modular design and frequent, effective interactions between developers and users has positively affected the design, implementation, support, and modifications of the NIS. It demonstrates the success of collaboration between engineering and medical communities, and more importantly the feasibility for technology readily available in a modern country to contribute to healthcare delivery in developing countries like Kenya and other parts of sub-Saharan Africa.

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Introduction

In late 2001, faculty from the Indiana University School of Medicine, Moi University, and Moi Teaching and Referral Hospital in Eldoret, Kenya launched a program to treat HIV-infected patients. The program, referred to as AMPATH (the Academic Model for the Prevention and Treatment of HIV/AIDS), started small, caring for a few dozen patients in one urban and one rural clinic.[1,2] By Sept 30, 2007, AMPATH had expanded to 18 clinics serving over 60,000 HIV-infected patients, with approximately 1,500 new patients being enrolled each month. Initially, deaths among patients with AIDS were high despite treatment with antiretroviral drugs.[3] One anticipated contributing factor to this high mortality rate is malnutrition; food supplementation has been perceived by clinical staff to produce a dramatic effect on lowering early mortality, however to date nothing has confirmed this. Consequently, AMPATH developed a comprehensive nutritional support program[4] that as of this writing includes four production farms, each producing more than 4,000 kg of food per week, and basic food supplements from the World Food Programme and the U.S. Agency for International Development (USAID).

By late 2005, the size and complexity of the AMPATH nutrition program began to overwhelm its operators. In

Affiliations of the authors: School of Industrial Engineering, Purdue University, West Lafayette, IN (JLL, YY, THL); Regenstrief Center for Healthcare Engineering, West Lafayette, IN (YY, MAL); Academic Model for the Prevention and Treatment of HIV/AIDS, Eldoret, Kenya (CG, WMT, TJP, JJM); School of Medicine, Moi University, Eldoret, Kenya (WMT, JJM); Department of Medicine, Indiana University School of Medicine, Indianapolis, IN (WMT, JJM); Department of Industrial and Manufacturing Engineering, North Dakota State University, Fargo, ND (JZ); Weldon School of Biomedical Engineering, Purdue University, West Lafayette, IN (MAL).

response, the School of Industrial Engineering at Purdue University and the Regenstrief Center for Healthcare Engineering joined the AMPATH collaboration in an effort to resolve food distribution difficulties. At the time, the food distribution office served approximately 2,000 patients and their dependents (inclusive of all household members), was growing rapidly, and did not have an efficient means to manage the AMPATH nutrition program's expanding information management needs. The goal was to build an electronic NIS that performed two fundamental functions. The first was to store patient nutritional prescriptions (see Appendix A, available as an online data supplement at http://www.jamia.org) written by nutritionists during patient enrollment in AMPATH and periodically thereafter. The second function was to use the stored prescriptions to compute daily food demand for all AMPATH food distribution centers and to manage the supply and movement of fresh produce and nutritional supplements. To achieve this, the NIS was designed to use principles from a Just-In-Time manufacturing system,[5] with the right quantity of properly packaged food arriving to every distribution center at the right time. The NIS was also integrated with AMPATH's medical record system[6,7] to support reporting and outcomes research.

Background Literature

The HIV/AIDS pandemic is a large problem globally, with more than 33.2 million (30.6 million–36.1 million) people living with HIV. The vast majority of those affected by the pandemic is from sub-Saharan Africa [22.5 million (20.9 million–24.3 million)].[8] This is largely due to the widespread poverty, inadequate health systems, and lack of education in the region. To understand the impact of HIV/AIDS, Piot explains three fundamental problems related to the disease.[9] (1) It primarily affects young adults, leading to economic problems from lost productivity, and high number of orphans left behind. (2) HIV affects even the educated and skilled, further augmenting the economic problems. (3) AIDS carries a stigma not seen in modern times. Piot further discusses the impact with the example in which Zambia lost 1,300 teachers in the first 10 months of 1998, accounting for approximately two-thirds of all new teachers trained annually. Due to the large impact the disease has, the United Nations Security Council recognized AIDS as an issue of human security in 2000.

In 2007, a new partnership called the International Health Partnership was established to address the structural inadequacy of health systems in the world's poorest nations.[10] In a press conference, Great Britain's Secretary of State for International Development Douglas Alexander notes that "developing nations have stressed for years that building health services is more important to long-term sustainability than focusing on international aid on specific diseases", and the partnership aims to help achieve that.

The partnership is another step in developed countries turning more attention to the global health problem. Developed countries not only have ethical motives in targeting global health problems, but it is also within their own interests. As Gostin stated: "It is axiomatic that infectious diseases do not respect national borders"[11]; with the advent of easy international travel, infectious diseases can easily

and rapidly spread throughout the world, and even developed countries are susceptible. The development of the NIS hopes to aid in the global effort in combating the HIV/AIDS pandemic, and as with the partnership, support the development of the health care infrastructure in Kenya.

The development of the NIS specifically targets the health care delivery system of Kenya's health care infrastructure. In his discussion, Bloom identifies that "delivery systems are inadequate or nonexistent across much of the world, as shown by the failure to make progress against [tuberculosis], despite the widespread availability of effective remedies"[12]. A search has revealed a lack of literature on structured food delivery systems in the developing countries. Current practices for food aid are providing standardized food rations to families through schools or direct distribution via trucks (food would be scooped to people who approach). Little information is gathered from either method to support their healthcare systems, and the NIS hopes to alleviate the problem; gathering data for future research to promote continual improvement of healthcare delivery in Kenya.

AMPATH's Food Distribution System

The AMPATH food distribution office is located in the AMPATH Center on the grounds of the Moi Teaching and Referral Hospital (MTRH) in Eldoret, Kenya. With a population of approximately 400,000, Eldoret is Kenya's fifth largest city. It is located approximately 180 miles northwest of Nairobi, the country's capital. In October 2005, the office served 2,220 people, distributing 19 tons of food per month via 8 distribution centers. At the time of this writing, the AMPATH nutrition supplementation program has expanded to 20 distribution centers serving approximately 30,000 people per week, distributing more than 200 metric tons of food a month. The distribution centers receive both dry and fresh foods. Dry foods are provided by WFP and USAID, while fresh foods are grown by AMPATH production and training farms (known as the HAART and Harvest Initiative (HHI)[13]) and by some AMPATH patients on their own subsistence farms. Selected items such as milk and eggs are purchased from local markets. Dry foods are shipped into Kenya and delivered to AMPATH packing centers, where they are repackaged into smaller bags, portions being dictated by the nutrition prescriptions written for AMPATH patients and their families. Repackaged food is then transported by the program's trucks to 20 distribution centers located throughout AMPATH's catchment area, within walking distance of each patient's home. Items distributed by the AMPATH nutrition program are shown in Table 1.

At the time of his/her first AMPATH clinic visit, each patient is interviewed by a nutritionist who performs a standardized nutritional assessment. For patients found to be food insecure due to poverty or physical disability, a formal nutrition prescription is written to meet the patient's personal and family food needs for 4 weeks. The patient is re-evaluated at routine return AMPATH clinic visits (monthly for those on antiretroviral drugs, quarterly for others). At 6 months after enrollment, a formal weaning form (see Appendix B, available as an online data supplement at http://www.jamia.org) is administered. If the patient is still food insecure, he/she and his/her family will receive another 6 months of nutritional supplementation. All

Table 1 ■ Detailed List of Food Distribution Program Items

Item	Source	Type
Maize	WFP	dry
Beans	WFP	dry
Corn and soy blend (CSB)	WFP	dry
Vegetable oil	WFP	dry
Foundation plus	USAID	dry
First food	USAID	dry
Advantage	USAID	dry
Maziwa Lala	HHI	fresh
Eggs	HHI	fresh
Sukuma Wiki	HHI	fresh
Sukuma Siku	HHI	fresh
Managu	HHI	fresh
Saga	HHI	fresh
Kunde	HHI	fresh
Amarynth	HHI	fresh
Spinach	HHI	fresh
Cabbage	HHI	fresh
Carrots	HHI	fresh
Pumpkin	HHI	fresh
Tomatoes	HHI	fresh

patients are weaned from the program within 12 months. The patient's entire household is fed, as feeding just the patient would most likely lead to the patient sharing any food provided.

When nutrition prescriptions are issued, patients select their preferred distribution center, the day of the week they will pick up food (limited to the operating days of their preferred distribution center), and the frequency with which they will be picking up food, ranging from weekly to monthly. This process provides flexibility for the patients to accommodate individual transportation, child care, and other issues preventing them from obtaining their food. The outcome is increased patient compliance in obtaining food aid and satisfying nutritional needs. Figure 1 provides an overview of the food distribution program.

Designing the Nutritional Information System (NIS)

This section of the paper highlights four major design aspects of the NIS. The first is a modular design based on functional needs of the system; the subsection discusses in chronological order the evolution of the system and its modules. The second design aspect is on the database design which highlights the hierarchical nature of the table design, the application of a concept dictionary, the use of relational database design, and the data model. The third subsection covers the user-interface design and key features to support the effective use of the system. The final discussion of the section is on the networking design which enables multiple and remote access to the system.

Modular Design Based on Functional Needs

In designing the NIS, several practical criteria were crucial for system design and implementation. The system was developed under live conditions, serving AMPATH clinics while still under development, gradually supplanting the failing paper-based system. As a result, the system was designed modularly; modules were rolled out as soon as they were developed and tested. Fluctuating AMPATH

specifications and feedback from food distribution staff using the NIS required ongoing modification of existing modules and system reconfiguration.

Patient Prescription Module

The first module to be completed—the *patient prescription module*—contains information from patient nutrition prescriptions. This serves as input to all NIS modules. Thus, designing data entry and editing capabilities was an essential first step for encoding patient prescription and personal profile data. To enhance migration from the paper-based system to the NIS and reduce data entry and management errors, the data input interface was designed to emulate the structure of pre-existing forms and processes (Appendix A, Figure 2). The editing feature is necessary tool to correct errors and to maintain data quality; but no historical logging is kept for any information edited via this method. As a safeguard, each edit requires confirmation of the user's intent to change the data.

Patient Pickup Module

The next module completed—the *patient pickup module*—forms part of the data gathering for distribution output. When patients picked up food from distribution centers, distribution workers document in a log (maintained at each center) the amount of food the patient or his/her proxy receives. This information is also recorded on the patient's prescription form (previously forwarded to the patient's preferred distribution center), and on a carbon copies of the patient's prescription form which the patient carries and is sent back to the distribution office. The forms received by the distribution office are entered into the NIS pickup module to keep track of data on food dispensed at various distribution sites. It also records instances in which food was not picked up; unclaimed food is not returned to the packing center, it is taken into account when preparing subsequent deliveries. This use of undistributed food was especially critical for fresh produce which had a limited shelf life of 2–3 days.

Demand Reporting Module

Due to the critical need for supply information at this point in development, a *demand reporting module* was developed next. This module collated demand by patients for food, and generated real-time supply reports for delivery. Original system designs planned for use of a materials requirement planning (MRP)[14] system to ensure food delivery in the right amounts at the right time, allowing for average delivery and handling times to minimize inventory levels. However, the immediate need for reporting capabilities by the distribution office resulted in the implementation of simplified reports, reports that only accounted for demand without considering
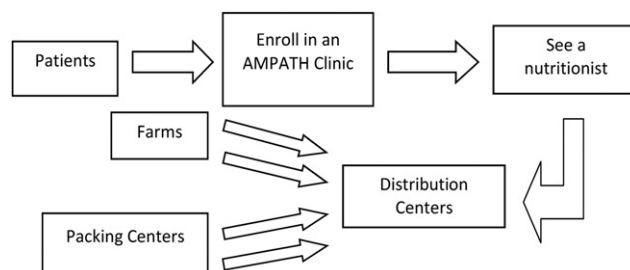

F i g u r e 1. Food distribution program overall process.

Figure 2. NIS/Paper prescription form comparison.

current inventory and required buffer levels. Distribution office personnel manually scheduled delivery times using the generated demand reports and sent the required amount of food as listed on the reports plus a buffer amount to account for prescriptions issued in the interim days between report generation and food distribution. The demand report module generated three separate reports for the farms, packing centers, and distribution sites. The different reports catered to the required information for each location by differentiating the types of items available at the specified location. Demand figures were calculated via a hard coded allocation chart where distribution sites were served by specific farms and specific packing centers as shown in Table 2 (available as an online data supplement at http://www.jamia.org). The allocation chart was based on early data collected from the distribution center, packing center, and farm site locations. Demand reports could be generated for a 10 or 30 working day period.

Patient Family Register

The three modules described above formed a functional system that could handle the basics of the food distribution system. The next module, the *patient family register*, was developed to record and track patient dependents (as previously mentioned, food was prescribed for both the patient and the patient's dependents). This provisioned the necessary data to generate monthly reports documenting the demographic and food distribution data for all persons receiving their dry food supplements as required by WFP and USAID. Because the average family included four to five children,[3] the family register was significantly larger than the prescription database. Since most dependents were not AMPATH patients, and thus had no AMPATH identifica-

tion numbers, the patient's AMPATH identification number was used as the index to locate any person in the system. Data maintained by this module is not as comprehensive as the prescription module, collecting only general personal data of dependents.

Multi-user Access System

The last module to be developed was the *multiuser access system*. Due to the rapidly expanding size of AMPATH and its nutrition program, several personnel had to be able to access, enter, and/or edit data at the same time. During the implementation of this module, the database was migrated to a server room in the AMPATH Centre and NIS personnel accessed it via one of two methods; the distribution office could access it via the local network, while the development and support teams could access the NIS via the Internet. MySQL database built-in network functions were used to accomplish this.

Database Design

Because of AMPATHs urgent need for an information system for their food distribution program, the NIS was implemented in steps as new modules and functionalities became available. To facilitate this, the database was designed supported by two methodologies, a hierarchical table design and a concept dictionary.

Hierarchical Table Design

The NIS system was developed in modules to coincide AMPATH's food distribution program being fully operational. Data tables for each module were linked via a master table containing unique identification numbers for all patients or dependents entered into the system. Identification numbers are generated sequentially (next available) by the

master table for new individuals being entered into the system. To assist AMPATH data entry personnel in recognizing patients and dependents with multiple identifiers (i.e., identification numbers for both the AMPATH program and for AMPATHs Orphan Vulnerable Child (OVC) program), the NIS was designed to compare individuals via logical comparisons of data fields. The unique identifiers would be used internally within the NIS data hierarchy to avoid confusion between modules.

Module data tables are then laid out below the master table. Figure 3 (available as an online data supplement at http://www.jamia.org) shows this using an imaginary patient's records in the patient prescription module. Figure 5a represents the patient's entry with the unique NIS identifier in the master table. Figure 5b illustrates the patient's entries in the patient prescription module—patient information table. A column in the table stores the unique NIS patient identifier to associate the patient. The table also generates a unique prescription number for each prescription entered to provide a link to the next table in the hierarchy. Figure 5c shows the food items and quantities corresponding to the patient's prescription in 3(b). Note that the prescription items use the prescription number to link data to the patient prescription.

The hierarchy table design allowed for historical tracking of information and changes in data, e.g., in the monthly prescriptions for patients, using timestamps and sequential identifier generation. The table structure also allowed for data from multiple prescriptions to be recorded for each patient. In addition, it eased data extraction via a single reference number which can be quickly found in the master table. All of this was especially useful for monitoring the recovery progress of a patient with relation to their nutritional supplement.

Concept Dictionary and Relational Database Design
As the food distribution program expanded, the database had to be modified to reflect the additional distribution centers, farms, packing centers, food items, etc. To handle this constant evolution without modifications to table structures, the NIS database uses a concept dictionary[15] and relational database design. Like a dictionary, the columns in the tables describe a concept, i.e., food items and quantity. Following a relational database design each possible response in a concept is assigned a reference number; entering the dictionary number or term name allows each concept in the dictionary to be linked to that data entry. An example of such a concept dictionary table is shown in Table 3 (available as an online data supplement at http://www.jamia.org). In Figure 5c, the relational database design can be seen in use. In the prescription the first item the patient is prescribed is 5 units of item 2, which from the dictionary in Table 3 is beans in kilograms.

Database Layout
With the development and implementation of each module, new requirements emerged as users began to understand the system's potential to organize and facilitate food distribution operations. To accommodate these, the database was designed for easy modification and expansion without affecting usability. In addition to the two methodologies described, as new system modules were developed, they were based on their own independent data tables, i.e., the data tables of previously implemented modules were modified as little as possible. New modules avoided storing data pre-existing in other modules by cross-referencing as necessary to ensure data consistency and prevent redundancy without compromising the functionality of previously implemented modules and to prevent duplication of data.

The modular development and hierarchy table design allowed for sections of the NIS to be developed independently without adversely affecting other modules. It also helped maintain the database structural integrity as modules did not overlap and overwrite each other. Figure 4 (available as an online data supplement at http://www.jamia.org) shows the most current database model with relations between the various modules laid out like a spider diagram, centering with the master table, for visual ease. Note the lack of the *demand reporting module* and the *multi-user access module* in the database model as the modules receive input data from other modules and do not maintain any tables of its own. Figure 6 also illustrates the independence of each module, with no relations to data tables belonging to other modules except concept dictionaries which were created to be shared across the system for additional data consistency.

User-interface Design
An easily navigable user interface is the key to success of complex information systems such as the NIS that could be prone to human error. Human errors can be reduced by enforcing checks within the system while processing any data entered and reflecting the status of these checks to the user. The development of the NIS interface took this into account and made use of large lucid buttons for system navigation, required confirmation of many data altering actions, and provided frequent feedback via text dialogs. To reduce complications and training for data clerks using the system, all data entry forms were designed to mimic the actual paper forms used to record data at the point of service as shown in the comparison in Figure 2. This exemplifies the interface design trying to keep in tandem with paper forms used by the distribution office. As the system was developed live, constant consultation with data staff aided in creating a simplified but comprehensive user interface for the NIS. However, mimicking the paper forms required developers to continually modify the data entry screens as the paper forms evolve to enhance use at the point of care.

The layout of the main screen for the NIS was created with consideration for the main uses of the system. The two main functions most commonly accessed were the patient/family information (consisting of the prescription, pickup, and family register modules) and reports. The prescription, pickup, and family register modules were categorized together as they dealt with all the data input and management of the system. Figure 5 shows the main screen of the NIS where 4 buttons are found (one navigates to the patient/family information and the other three navigate to the three different types of standard reports).

The patient information button navigates to a screen with two menus: one for the selection of patient related functions (patient prescription, and pickup modules) and one for family related functions (patient family register module). This identifies clearly to the user items relating to patients and items relating to the family of patients. Entering data
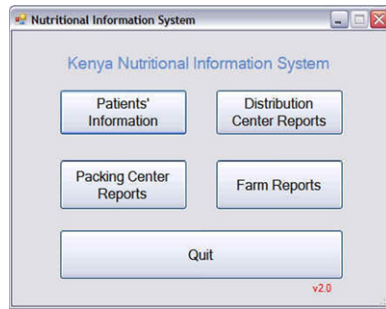
F i g u r e 5.   NIS main screen.

into the forms was further simplified using automatic completing functionalities. For example, entering the AMPATH identification number of a patient already in the system will trigger the system to load selected information about that patient, thus supplying existing data for most of the patient identification fields.

For functions which there were no paper forms to reference for design, a simplified screen was created based on feedback from data managers and the food distribution leaders and staff. Again the fundamentals described earlier for interface design were followed to reduce human error and maintain simplicity. Repeated iterations of user feedback and system modifications were the key to enhancing system usability and minimizing errors. Figure 6 shows the interface design used for family register data entry.

The reporting function was assigned to three different buttons on the main screen shown in Figure 5 to clearly differentiate the types of reports the NIS was able to generate. Navigating to any of the reports led the user to another screen where the user could choose between reporting for 10 or 30 working days. The user would specify the starting date and location of the report they require—either a particular distribution center, packing center, or farm depending on which reporting function they are using. Figure 7 (available as an online data supplement at http://www.jamia.org) is an example of a 30-day report generated for the distribution center at Chulaimbo in November 2006.

Network Design
The size and complexity of the food distribution program and the data required to run it necessitated having multiple users enter data into the NIS simultaneously. Having multiple users to access the database requires the database to handle multiple queries. The programming design and system structure supporting a multi-user environment is beyond the scope of this paper but can be obtained from the MySQL database manual.

The network design places the server in a centralized location in the AMPATH Centre which is equipped with a Local Area Network (LAN). Individual NIS users within the AMPATH Centre are able to access the server through the LAN and enter data or make modifications to the NIS. Although multiple users can enter data or edit a record at any one time, individual records in any database can only be accessed by a single user at a time. When a user enters a patient's identification number, the NIS locks that record, preventing access by any other user. Although the NIS server is connected to the Internet and is therefore accessible

to NIS developers in the United States, Kenya's lack of high-speed Internet service prevents optimal remote use of the NIS at this time. Future development of high-speed broadband Internet access in Kenya (currently underway for the MTRH) could potentially support a thin client infrastructure for remote entry of data into the NIS.

Impact of the NIS
Prior to the inception of the NIS, the AMPATH program relied heavily on spreadsheets and constant communication over cell phones to distribute food to the needy program participants. At its peak, the program managed to support 2,000 patients in this method, but it quickly started to show signs of strain and inability to satisfy the increasing demands of the program; patient enrollments were increasing faster than anticipated and food donors were very supportive of the program, pledging to continue and increase their support.

With the completion of version 2.0 of the NIS, the AMPATH food distribution operations has been able to function at a much higher capacity; the number of persons fed increased from 2,000 to 30,000 persons per week. This translates to a short term impact of 28,000 more lives affected, and given a greater chance of survival, weekly within a short period. In the long term, the NIS has capacity to support further expansion the AMPATH nutrition program to reach out to more patients. As of February 2009, AMPATH has enrolled 89,000 patients cumulatively, inclusive of all AMPATH patients but does not include family members which are fed as part of the AMPATH nutrition program. To visually demonstrate the increased traffic to AMPATH, Figure 8 shows the number of patient visits over the years by month. Note that a marked increase in patient visits can be seen during the NIS development and deployment period and it continues to increase postdeployment.

In addition to the patient impact, the system affects the AMPATH nutrition program staff. It provides a means to spread the massive workload and allow for an otherwise time-consuming, practically impossible hand-managed task to become manageable, allowing for the number of staff working in the AMPATH nutrition program to more than double.

The system also supports the AMPATH program in streamlining distribution operation and makes it more efficient and

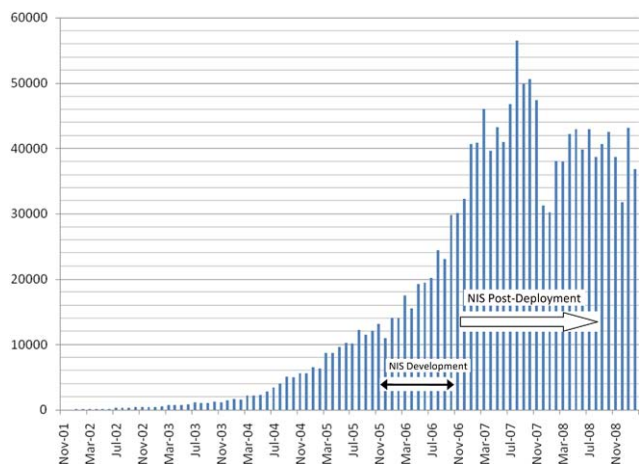**F i g u r e 6.**   NIS family register data entry interface.

F i g u r e 8. Patient Visits by Month: Nov 2001 to Feb 2009.

cost-effective by better logistic planning and execution. Additionally, to operational and end-user impacts, the system also provides data for clinical epidemiological studies, for example, studies on demonstrating the effects of nutrition supplementations on patient outcomes such as immune reconstitution (e.g., increase in CD4 lymphocytes) and reduced incidence of AIDS-related infections.

Finally, food donors are constantly provided with operation reports, demonstrating the success of the AMPATH nutrition program and leading to promises for enough food to feed all AMPATH patients and their families with food insecurity. This has undoubtedly resulted in many lives saved.

In this way, NIS developers have partnered with AMPATH clinicians and ancillary program personnel as an integral part of the AMPATH care team. Overall, the deployment and use of the NIS contributes to the health care delivery structure in Kenya, with the ability to extend to other parts of sub-Saharan Africa.

Discussion and Conclusion

The NIS is being used to support food distribution for 30,000 persons per week through the AMPATH program in western Kenya. Through an iterative process of development, use, modification, assessment, and further modifications, the NIS has evolved into an effective system for delivering food to malnourished persons in a developing country with limited infrastructure. The NIS' modular design and frequent, effective interactions between developers and users has positively affected the design, implementation, support, and modifications of the NIS. It demonstrates the success of collaboration between engineering and medical communities to fight AIDS, and more importantly the feasibility for technology readily available in a modern country to contribute to health care delivery in developing countries like Kenya and other parts of sub-Saharan Africa.

In continuing to improve the AMPATH nutritional program, the future development for the NIS aims to include:

1. creating a more dynamic user interface to better support ongoing needs of AMPATH's Food Distribution Program
2. establishing more detailed and customized reporting functions required by a robust accounting and MRP system
3. creating a module supporting detailed inventory management
4. real-time linking of the NIS to the AMPATH Medical Record System to enhance data sharing between the NIS and related AMPATH programs, such as Social Support, Orphans and Vulnerable Children, and Economic Development.

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