A Data Driven Policy to Minimize the Tuberculosis Testing Cost Among Healthcare Workers

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Abstract

Background

The Centers for Disease Control and Prevention mandates that healthcare employees at high risk exposure to Tuberculosis (TB) undergo annual testing. Currently in the US, two methods of TB testing are commonly used: a two-step skin test or a whole-blood test. Each testing method has unique costs and considerations. Healthcare leadership's test selection must not only account for direct cost such as material, procedure and resources, but also indirect costs such as employee workplace absence. Our purpose was to build a mathematical model to investigate the value loss perspective of these testing methods and assist leadership in their decision-making.

Methods

This model is based on an Upstate South Carolina healthcare employer's costs affecting over 18,000 employees on 6 campuses. A process flow map identified the variations in TB testing methods that incorporated the varied material and procedural costs based on the Mantoux two-step tuberculin skin test (TST) and the Interferon-Gamma Release Assay test (IGRA). In addition to these direct costs, the subject's time requirements involved with each test for 4 employee types and 6 travel-to-testing-site times were calculated.

Results

Regardless of direct cost variations, a switching point between testing procedures that minimized total system costs was most influenced by employee salary. In this model, an employee who is paid more than $48/hour should undergo IGRA blood testing irrespective of the travel time. As employee pay rate decreases to $30/hour, TST testing becomes more economical. Assuming an equal number of at-risk employees in each wage and travel category, switching from the current policy of 95% TST testing to integrated TST/IGRA testing would reduce TB compliance cost by 28%.

Conclusions

Mathematical modeling can assist healthcare system decision-makers in understanding the implications of employee TB compliance testing. This model distills the known direct costs of TST compared to IGRA testing and value loss perspectives of employee time into a definable switching point. Although actual costs and potential dollars saved depends on TB testing compliance rules and regulation, it appears that a mixed model of TB testing may be the most cost-effective approach for a large health care employer with multiple campuses.

1. Background

Tuberculosis (TB) is an airborne disease caused by Mycobacterium tuberculosis. Although it typically infects the lungs, it can attack other organs including the spine, brain, and kidney (1). TB infections take on one of two forms; latent or active. In the latent form, TB bacteria in the body is suppressed by the immune system. Hence it is asymptomatic and incapable of spreading between individuals. However, infected individuals can progress to active TB disease months to years later (2). In the active form, it is symptomatic and highly contagious. Both forms are detectable by routine TB monitoring and with a properly executed monitoring programs outbreaks can be mitigated. Healthcare employees are a high-risk population that is susceptible to TB because of the exposure to unsuspected or undiagnosed TB infected patients. (3). In 1994, Centers for Disease Control and Prevention (CDC) published guidelines on infection control policies and practices that are intended to reduce the risk of transmission of TB in healthcare facilities which was recently updated in 2019 (4). According to the new policy, annual TB testing of healthcare personnel is not recommended unless there is a known exposure or ongoing transmission at a healthcare facility. However, any existing employees with untreated latent TB infection should receive an annual TB testing. Additionally, it is highly recommended to consider using annual TB screening for specific groups at increased occupational risk for TB exposure (e.g., pulmonologists or respiratory therapists) or in particular settings, if a transmission has occurred in the past (e.g., emergency departments). Prior studies have reported that strict maintenance of the CDC policy has helped in reducing the infection of TB among healthcare workers (3, 5). Clearly, the TB testing policy adopted by a health system affects the program maintenance cost.

Currently, two widely adopted testing procedures exist; the first and oldest test is the Mantoux tuberculin skin test (TST). This test involves an injection of 0.1 mL of liquid containing 5 tuberculin units into the top layer of the forearm. Once injected, the test is read 48–72 hours later by a trained clinician, usually a registered nurse (RN), and the outcome is interpreted using a ruler to measure the diameter of possible induration of the area. If no induration occurs, then the test is reported negative; whereas if the diameter of the indurated area exceeds 10 mm, then the test is considered positive. In the case of a negative test result, the second step of testing is administered, which is similar to the first step. Whereas, in case of positive reading, further testing is performed to evaluate for TB disease, which includes a physical examination and an X-Ray. If for any reason the patient does not return in the stipulated timeframe to have the test read, the testing must be repeated from the first step. Although used predominantly, TSTs are not perfect and various factors may produce a false-positive result. Infection with nontuberculous mycobacterium is one example. In the case of patients that have previously received the Bacille Calmette-Guerin (BCG) vaccine, TSTs could record a false-positive result (6). Finally, clinician interpretation of the TST is subjective and requires manual measurement that may influence reporting, especially in borderline cases. Despite being a 2 step, 2-day process with limitations, TSTs are still adopted by the majority of health systems as the preferred method of testing among employees.

The other testing procedure are whole-blood Interferon-Gamma Release Assays (IGRAs). IGRAs are quicker and do not require multiple visits to the facility. Instead of injecting a patient and waiting 48–72 hours for an immune response, 1 to 3 vials of blood are drawn from the patient and sent to the lab for automated testing. Two IGRAs are available in the US: the QuantiFERON-TB Gold In-Tube test (QFT-GIT) and the T-SPOT.TB test (T-Spot). QFT-GIT test involves the collection of three tubes of blood (a positive control, a negative control, and a test) that are sent to a laboratory, and they are tested within 16 hours of collection. In the lab the concentration of interferon gamma (IFN-g) is measured. The T-Spot test differs from the QFT-GIT in that it only requires one tube of blood to be drawn and measures the number of IFN-g producing cells. IGRAs have a few advantages over the TSTs: they require only a single visit for a blood draw, results can be available in less than 24 hours, and prior BCG vaccination does not cause a false-positive IGRA test result. However, the IGRAs are costlier than the TSTs. On average IGRA supply costs are \$30–38 higher than a TST (7). Additionally, the blood testing must be completed within a time frame and some facilities do not have the in-house capability to test the sample. Both TST and IGRA tests require the patient's skin to be punctured with a needle.

Under the new CDC mandate, the cost incurred by a health system for maintaining a TB testing will reduce as it does not require all existing employees to undergo annual TB testing. However, it is still essential to conduct a cost analysis as TB screening is a time-consuming process and results in loss of employee's productive working hours. While prior research has focused on comparing the effectiveness of a TST to IGRA for detecting TB, very few have investigated the overall system costs of these processes (8, 9). For example, a TST requires a minimum of three (with the potential for five) visits to the facility, compared to a single visit with IGRAs. Hence it is crucial to identify which screening process should be recommended for an employee who requires testing based on the direct cost and indirect costs of testing.

The studies that have evaluated the cost of TB testing for a health system have considered only the direct cost associated with the testing procedure (10). TB testing incurs a direct cost like all laboratory testing; these direct costs include the material cost, procedure cost, and resource cost. However, the healthcare organization will incur an additional indirect cost resulting from an employee's absence from the workplace during testing. A microscopic view indicates that the indirect cost depends on four factors: time taken to travel to the facility, the time spent in the facility, missed employee work hours and the hourly wage or salary of the employee. Although a few studies have considered the indirect costs, to our knowledge, none of the studies have examined all the indirect costs discussed above (11).

Additionally, most of the cost comparison studies to date have focused on analyzing the cost of maintaining a TST and IGRA separately (12). Hence the conclusion was focused on recommending which specific TB testing method should a health system adopt. However, a more integrated approach of understanding how to blend the two testing methods may identify the ideal maintenance costs for the required TB testing program. This study was designed to explore whether a switching point exists in the selection of the most economical TB testing method in a large healthcare system.

2. Methods

2.1 Mathematical Model

This study used cost and time requirements involved in a test and combined it with two inputs: employee hourly wage and travel time to the facility. A mathematical programming model was developed to identify the switching point for various hourly rate and travel time combinations. This approach was adopted because of its flexibility to investigate different hypotheses, multiple combinations of inputs, and its proven efficacy as a decision-making tool in healthcare (13–15). A mathematical programming model includes an objective function (the result of choices or selections made within the model), combined with a set of constraints that represent the feasible or allowable choices, based on the assumptions and input parameters provided. This model was derived after the research team interviewed and solicited feedback form hospital policymakers, physicians and employee health stakeholders. Different combinations of the two key input parameters, employee hourly wage and travel time to the facility, were selected run through the model. This approach was intended to inform decision makers on the implications of policy decisions, as well as to include the end-user and account for the needs of policymakers (16, 17). Based on the input combinations, the developed model provides a recommended testing procedure for the healthcare system.

2.2 Studied Population

The study was based on the test costs and policies adopted at PRISMA Health - Upstate, South Carolina in August 2018. PRISMA Health is the largest not-for-profit health organization in South Carolina, serving more than 1.2 million patients annually with over 18,000 employees. Currently at PRISMA Health, approximately 95% of the existing employees who require annual testing undergo a TST while all new employees are selected for IGRA testing.

2.3 Study Design

After understanding each step and process flow of the two TB testing procedures, the mathematical model was created to identify the total cost and time requirements involved to test several employee types and travel distances to the testing facility. The goal of the mathematical decision model was to determine which test, TST or IGRA, an employee should undergo in order to minimize the total cost of the system. This study was considered Exempt by the Greenville Memorial Hospital IRB.

2.4 Skin Test (TST) Process Flow

As mentioned above, the TST testing procedure is a two-step process and requires multiple visits to the facility. Figure 1 details the process flow of the patient undergoing a TST testing process with different possible scenarios. If an employee misses one of these steps, the testing procedure is repeated from the first step. Thus, 6 possible scenarios for TST were included in this study.

1. (negative, negative) The employee tested negative in both steps.
2. (negative, positive + X-ray) The employee tested negative in the first step but positive in the second step, followed by an X-ray.
3. (positive + X-ray) The employee tested positive in the first step, followed by an X-ray.

4. (repeat, negative, negative) Same as scenario 1, but employee does not return within 72 hours and must repeat the test from beginning.
5. (repeat, negative, positive + X-ray) Same as scenario 2, but employee does not return within 72 hours and must repeat the test from beginning.
6. (repeat, positive + X-ray) Same as scenario 3, but employee does not return within 72 hours and must repeat the test from beginning.

[Insert Fig. 1 here]

2.5 Blood Test (IGRA) Process Flow

The IGRA testing procedure is a single step testing procedure. Figure 2 details the process flow of the patient undergoing an IGRA testing process with 2 possible scenarios.

1. (negative) The employee is tested negative for the test.
2. (positive + X-ray) The employee is tested positive and followed by an X-ray.

[Insert Fig. 2 here]

2.6 Notation, Data, and Model

The model was prepared to capture system costs per pathway based on the type of test, the employee hourly wage, and the employee travel time to/from the facility. It was assumed that the

employee health nurse tester and blood drawing costs and wait times were similar for each test. This corresponded to indices of TB test type *j* (where 1 = TST, 2 = IGRA), hourly wage *i*, and travel time *l* in the model. In addition, we denoted *k* as the scenario number for either test type. See formula notation in Table 1.

Table 1
Model notation for the TB test cost equation

Notation	Description
I	The set of employee types (or hourly wages)
J	The set of TB test options
K^j	The set of possible scenarios for TB test type *j*
L	The set of travel times to/from the facility
P_{jk}	Probability of test type j in scenario *k*
S_i	Hourly wage for employee type *i*
S^N	Hourly wage for the nurse administering test
W_{ik}	Total time spent in the system based on employee type *i* and scenario *k*
W_{jk}^N	Total time spent in the system by the nurse for test type *j* in scenario *k*
n_{jk}^1	Number of tests administered for test type *j* in scenario *k*
n_{jk}^2	0/1 flag indicating whether an X-ray is required for test type *j* in scenario *k*
n_{jk}^3	Total number of facility visits based on employee type *i*, test type *j*, and scenario *k*
T_l	Travel time to/from the facility for distance level *l*
C_j^1	Procedure cost for test type *j*
C^2	X-ray cost

2.7 Model Constraints

For the analysis, we restricted the employee salary (S_i) to four levels to cover the minimum and maximum salary for a full-time hospital employee. The salaries represented in Table 2 were derived from the wages of the respective employee type in the US (18). As employee travel times across a large health organization may vary greatly, the index for travel time (l) was divided into six 10-minute levels, with threshold values ranging from 10 minutes to 60 minutes, as seen in Table 3.

Table 2
Hourly wage for four employee types.

Index	Employee Type *(i)*	Hourly Wage *(S_i)* in dollars
1	Physician	150
2	Administrator	48
3	Nurse	30
4	Technician	17

Table 3
Possible round-trip travel times between home and facility

Index for travel time *(l)*	Travel Time *(T_l)* (in mins)
1	10
2	20
3	30
4	40
5	50
6	60

Finally, Tables 4 and 5 provide the per-scenario breakdown of the process flows for TST and IGRA testing. Note: In the case of TST, a physician is not required to return for reading the test. Assume that $i = 1$ denotes a physician, then $(n^3{}_{11k})$ shows one less visit than $(n^3{}_{i1k})$, $i \neq 1$.

Table 4
Probabilities and number of visits for each scenario under TST

Scenario *(k)*	Probability *(P_{1k})*	# of tests administered for TST *($n^1{}_{1k}$)*	# of facility visits *($n^3{}_{i1k}$), $i \neq 1$*	# of facility visits for physicians *($n^3{}_{11k}$)*
1	0.98	2	3	2
2	0.1	2	4	3
3	0.5	1	3	2
4	0.3	3	4	3
5	0.1	3	5	4
6	0.1	2	4	3

Table 5
Probabilities and number of visits for each scenario under IGRA

Scenario (k)	Probability (P_{2k})	# of tests administered for TST (n^1_{2k})	# of facility visits (n^3_{i2k})
1	0.98	1	1
2	0.2	1	2

From the above data, per-employee cost Z_{il} for a procedure for each hourly wage i and travel time l is formulated as:

$$Z_{il} = \sum_{j \in J} \sum_{k \in K^j} P_{jk}(n^1_{jk}C^1_j + S_i W_{ijk} + S^N W^N_{jk} + n^2_{jk}C^2 + n^3_{ijk}S_i T_l) \quad (1)$$

$$Z_{il} = \sum_{j \in J} \sum_{k \in K^j} P_{jk}(n^1_{jk}C^1_j + S_i W_{ijk} + S^N W^N_{jk} + n^2_{jk}C^2 + n^3_{ijk}S_i T_l) \quad (1)$$

Considering that the overall objective was to identify the switching point from one testing procedure to the other for each (S_i, T_l) combination such that total system cost is minimized, the restrictions and assumptions do not appear to affect the efficacy of the model.

To execute such an algorithm, and identify lowest cost selected between the two TB test options, the following notation for this optimization problem is proposed.

Denote X_{ijl} as the decision variable such that:

$$X_{ijl} = \begin{cases} 1, & \text{if TB test } j \text{ is selected for hourly wage } i \text{ and travel time } l, \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

$$X_{ijl} = \begin{cases} 1, & \text{if TB test } j \text{ is selected for hourly wage } i \text{ and travel time } l, \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

The resulting cost minimization problem is shown below.

$$\min Z = \sum_{i \in I} \sum_{j \in J} \sum_{l \in L} X_{ijl} \left(\sum_{k \in K^j} P_{jk}(n^1_{jk}C^1_j + S_i W_{ijk} + S^N W^N_{jk} + n^2_{jk}C^2 + n^3_{ijk}S_i T_l) \right) \quad (3)$$

$$\text{subject to} \sum_{j \in J} X_{ijl} = 1, \quad \forall i \in I, l \in L \quad (4)$$

$$X_{ijl} \in \{0,1\}, \quad \forall i \in I, j \in J, l \in L \quad (5)$$

3. Results

Using Eq. (1), the primary research question, i.e., identifying the switching point between selecting TST testing vs. IGRA testing across a set of hourly wage and travel time combinations, was achieved. Figure 3 below represents the switching point from one testing procedure to the other based on hourly wages and travel time.

[Insert Fig. 3 here]

Figure 3 Assignment based on salary and travel time

Equation (3) represents the objective function to be minimized to obtain a minimum TB testing cost for the system. As mentioned earlier, currently, 95% of the existing PRISMA Health employees who require annual testing undergo a TST. The total cost Z under the current PRISMA Health policy to the new blended policy derived from the model was compared assuming 100 employees within each hourly wage *i* and travel time *l* combination, for a total of 2,400 employees. The total cost for the current and new blended policy is shown in Table 6.

Table 6
Total cost (Z) under two policies

Total cost (Z) under current PRISMA health policy	$311,108
Total cost (Z) under current new blended policy	$223,235

4. Discussion

Mathematical modeling can assist healthcare system decision-makers in understanding the implications of employee TB compliance testing programs. This model distills the known direct costs of Mantoux two-step tuberculin skin testing compared to Interferon-Gamma Release Assay laboratory testing and value loss perspectives of employee time into a definable switching point. Regardless of direct cost variations, a switching point between testing procedures that minimized total system costs was most influenced by employee salary. Based on the model, an employee who is paid more than $48/hour should undergo IGRA blood testing irrespective of the travel time. As employee pay rate decreases to $30/hour, TST testing becomes more economical if travel times are less than 10 minutes. Although actual costs and potential dollars saved depends on TB testing compliance rules and regulation, it appears that a blended model of TB testing may be the most cost-effective approach for a large healthcare employer with multiple campuses.

Clearly looking at the cost to purchase a TB test, TST or IGRA is suboptimal from both an employee and employer point-of-view. Multiple factors must be considered when adopting a system wide policy for TB testing. Employees and decision-makers may have different value metrics. For example, employees may value the easy of single visit with no requirement for follow up and the employer may value the reduced costs of one testing procedure over the other. Although cost effective, the proposed blended TB testing model with a switch point may have the challenge of messaging to employees that avoids perceptions of bias and discrimination of lower paid employees for successful implementation. This mathematical model does not address these other complex factors that decision-makers must address. This leads to an important question: if and how should we translate a mathematical model into policy?

With the current level of focus on healthcare cost reduction, decision-makers understand the importance of objective data. Mathematical modeling, even with its limitations, can assist decision-makers in assessing the ramifications of their decisions prior to implementation. For example, one approach to TB testing might consider having staff complete this testing on personal time thus reducing employee work lost to zero. But this cost saving measure would likely lead to low employee morale and job satisfaction. Alternatively, through understanding the true costs of employee travel time with this mathematical model, efficiencies in employee transport to the testing sites can be sought. In this way mathematical modeling can be an asset to decision makers.

5. Conclusion

This research focused on minimizing the TB testing cost among healthcare workers by considering both the direct and indirect costs associated with the testing procedures. It appears that mathematical modeling can inform decision makers on the total costs of an employee TB testing policy for a large healthcare system. The study observed that employee hourly salary and travel time to testing facilities are most influential in identifying a switching point in a blended TST and IGRA TB testing compliance program that minimizes system costs. Although the study identified a definable switching point between the two testing policies, how best to implement a blended TB testing compliance program should be the focus of future work.

Abbreviations

BCG
Bacille Calmette-Guerin
CDC
Centers for Disease Control and Prevention
IFN-g
Interferon gamma
IGRA
Interferon-Gamma Release Assays
RN
Registered nurse
TB
Tuberculosis
TST
Mantoux tuberculin skin test
T-Spot
T-SPOT.TB

QFT-GIT
QuantiFERON-TB Gold In-Tube

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

V.G and K.T analyzed the raw data, formulated and tested the mathematical model. V.G and R.P were major contributors in writing the manuscript and K.T reviewed the manuscript. D.S assisted in problem formulation and reviewing the manuscript. All authors read and approved the final manuscript.

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Figures

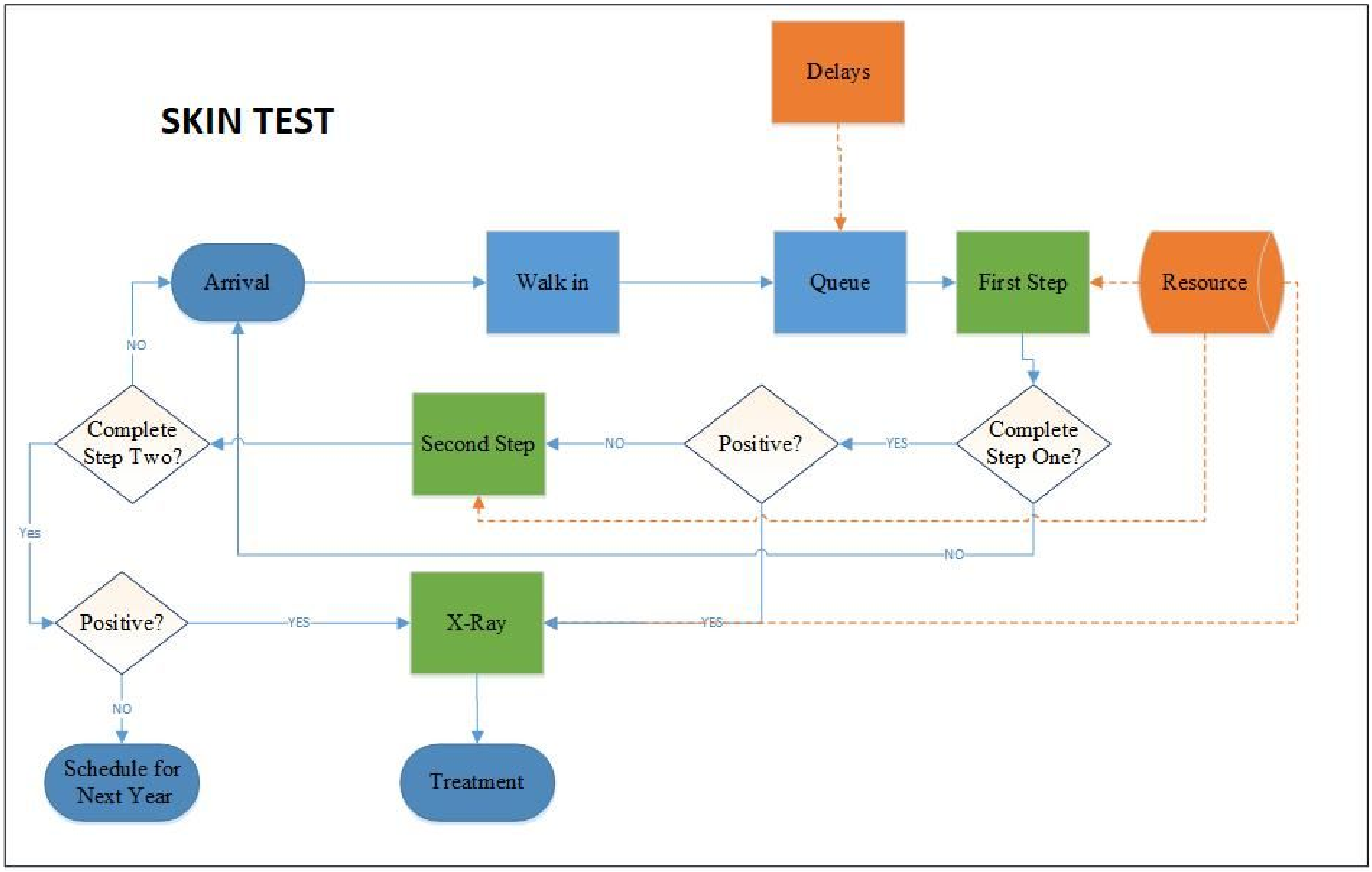

Figure 1

Skin Test (TST) process flow

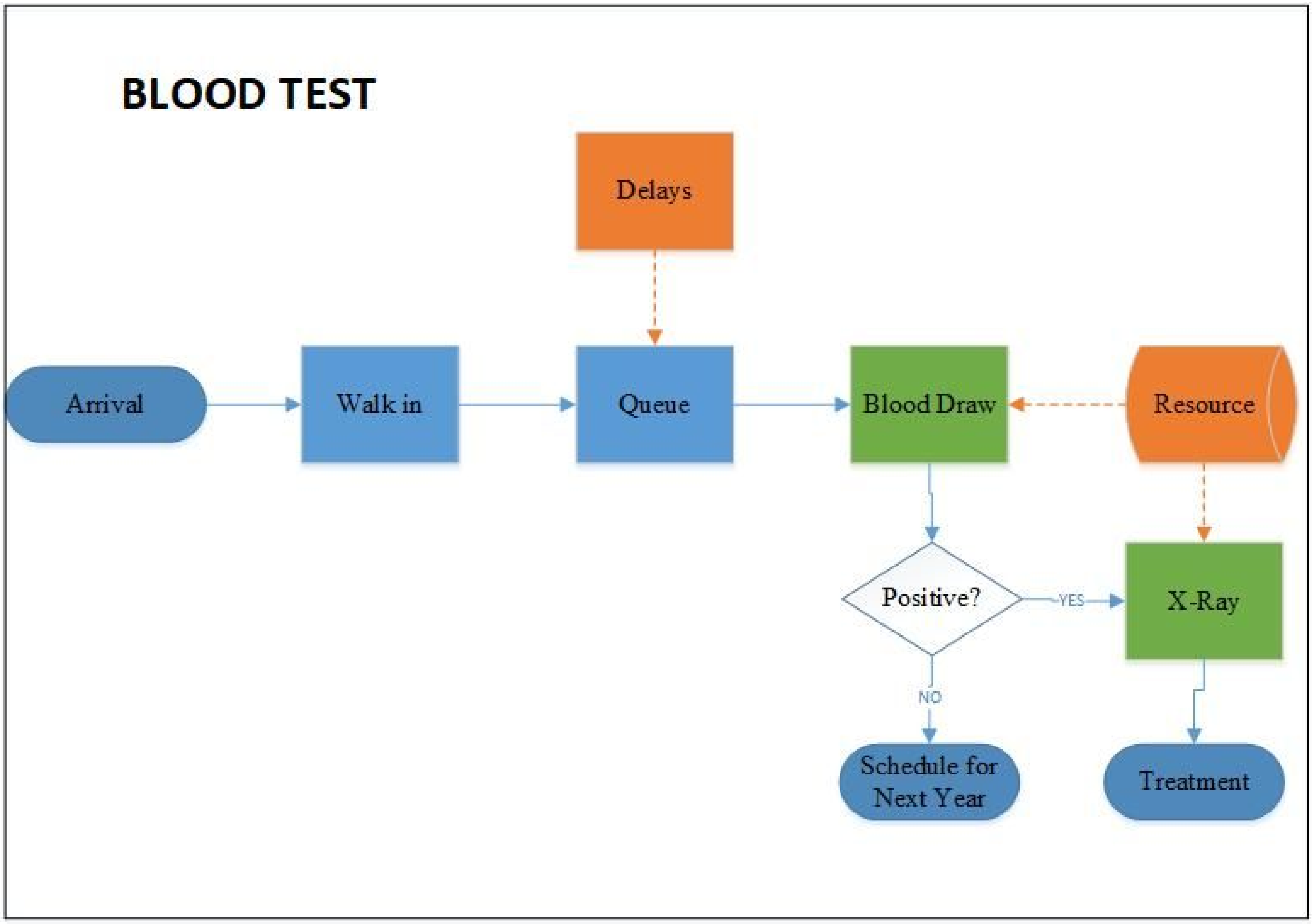

Figure 2

Blood Test (IGRA) process flow

Travel Time in (min)					
	60	IGRA	IGRA	IGRA	IGRA
	50	IGRA	IGRA	IGRA	IGRA
	40	IGRA	IGRA	IGRA	IGRA
	30	TST	IGRA	IGRA	IGRA
	20	TST	IGRA	IGRA	IGRA
	10	TST	TST	IGRA	IGRA
		17	30	48	150
	Salary in $/hr				

Figure 3

Assignment based on salary and travel time