Analysis of an Outpatient Consultation Network in a Veterans Administration Health Care System Hospital.

Alon Ben-Ari.

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Introduction

Many healtcare organizations face the challenge of scaling up effective health care delivery. There is a growing agreement that a better understanding of the structure of the healthcare system is needed to achieve that goal. Networks analysis provides the formal framework of thought to understand such systems. Given the definition of health care system as as a network of actors who aim to provide health care, the links to network anlysis is made very clear [1]. The network can be an integrated delivery system, a centrally controlled multi-hospital system or a virtual system composed of many partners like the one we observe in tele-health. In the healthcare community there is a growing interest in the understanding of the relationship between the structure of a healthcare network and care delivery. In this regard network analysis provides the intellectual framework to reason on issues of outcomes and cost but more importantly that of scale (i.e. different healthcare delivery regions) as it allows to capture the complexity of structure (medical/non-medical providers, private/public insurers etc.) and dynamics of healthcare on any scale in a rigorous manner.

Related Work

Health services research employing social network analysis focused typically on the human actors in the system. A survey [2] examining the application of of SNA as a part of an intervention to support the implementation of change in healthcare setting found a total of 52 completed studies of which only one was a part of an intervention to change practice. Most studies examined the interaction between healthcare providers and the influence the network had on practice, decision making and information dissemination. At any rate studies mostly used surverys and observations as sources and only a minority used administrative data. Moreover the data was collected at a set given time point.

Other examples of SNA application include the evaluation of public health service [3, 4], disease surveillance and management of outbreaks using social media [5]. To summarize SNA's application in healthcare are characterized by the following:

- Non scalable: The methodology used to collect data suggests small network of up to several hundred providers.
- Given the lack of longitudinal data on a clinically or operationally meaningful scale does not allow to make assertions on network evolution.

- Studies focused on social networks in the context of service provision/organization and behaviour change i.e. diffusion innovation, key opinion leaders etc.
- There are no SNA studies aimed at modelling the operation of large healthcare systems.

Given the paucity of applications of network analysis in healthcare in general and patient coordination of care in particular this project aims at exploring the feasibility of applying social network analysis to the issue of care coordination. Specifically this study will address the question of access to care. The dataset will include data from a large network of Veterans Administration (VA)hospital in the Pacific North West of the US. This study comes at a timely manner as the Veterans Affairs was scrutinized recently for falsfying records of patient's wait times which culminated in the replacement of the secretary of the VA and the enactment of the *Choice Act*.

Current Study

In this study we explore a network of outpatient clinics. This is a network of spatially distributed clinics and the services are rendered to patients by providers with variable degree of training. We attempt to model access to care measured as time to rendering a clinical consultation using network topography measures and make suggestions for reducing number of consultations and wait times.

Access to care is a key metric in the evaluation of *all* healthcare systems. The Veterans Administration (VA) Health Care System is not unique in this regard. Outpatient patient consultation remains the bulk of care delivered to patients. Yet, to this point there is no rigorous framework for the understanding of the mechanics of patient outpatient consultations.

In this study ambulatory outpatient consultation for VA facilities in the Veterans Integrated Service Network (VISN) in Washington state will be modelled as a network where clinical services serve as nodes. Edges between nodes exist if a clinical service consulted another service regarding a patient. This study aims to understand the 'time to consultation' in terms of the system's network topology measures (degree, betweeness, graph specral decomposition, graph clustering) and suggests changes to the topology of the network to effect an improvement to patient access to care allowing for more patients to be served in a shorter period of time with *no* change to number of providers. We suggest this is achieved by finding clinics from different disciplines which consult each other frequently and merge them into a single clinic thus eliminating the wait time for the patient and reduced overall load of requests. Furthermore, introducing a zero wait time consultation will achieve two goals: 1) off load clinics to see other patients thus shortening the wait time for all patients. 2) Since each consultation is associated with a finite chance of losing the patient for follow-up, by serving the patient on the same day, this risk is eliminated.

Methods

As a preliminary study we select Washington state for the analysis of its VAs and outpatient clinic consultations. The VA data warehouse was queried for all outpatient consultations in the period 2014-2015. Specifically we are interested in the clinic initiating the consultation request, the service carrying out the service, and time for completion of the consultation. Each node is assigned its median time for completion of consultation and each edge is assigned the sum number of requests made between its two ends. To get an

intuition about the network topology measures (i.e. components, degree distribution) were used as dependent variables for consultation period and consultation traffic.
To make suggestions about shortening wait time for consultation and reducing the number of consultations we suggest finding a combination of clinics which are frequently associated together and merge them - thus eliminating the wait time for a consultation between them. As a motivating exmple imagine surgeon consults an anesthesiologist about a patient and he in return thinks a patient needs to be seen before surgery by a cardiologist and that this merits a delay of surgery. It would be best if a consultation can be made the same day thus 'merging' the anesthesia clinic and cardiology clinic to eliminate the wait time. Moreover if the surgeon's clinic is available on that day meaningful decisions can be made).We explore several methods to linking nodes detailed below. Importantly we do not change the topology of the graph. Removing an edge or a node from the graph means this clinic is not available for other clinics to link to, or edges to create a triangle with. To reiterate, the practical point for the merging of clinic is to allow for patients to be seen by another clinic on that day.

- Model 1: naturally occurring triangles motif in the network are naturally occurring clinics which already seem to work together. Triangles can be 'merged' to a single clinic. By merging clinics we mean that patients who need to be seen by other discipline will be seen on the same day thus eliminating the wait time for and additional consultation. We report the time saved. which is he time eliminated by merging the nodes.

- Model 2: Pair and triple motif. A significant consultation traffic between a triple or pair of clinics suggests a clinically relevant work load for both clinics. We suggest that each node is merged along a path with one or two of its neighbours with the highest wait times . Merging them into a single node is reasonable clinically and operationally.

- Model 3: Find for any two nodes a node in the set of common nodes with the highest wait time. We merge each clinic with the clinic common to both. For example if A and B are nodes with an edge between them and C,D and E are the set of common neighbours of which E has the highest wait time value, than we merge A with E and B with E to save the time of E.

- Model 4: Merging a node with two of its highest ranking predecessors by Pagerank [6]. The intuition is that if a request is made from an *important* node, than it my require quick response, and merging the two clinics maybe beneficial. If a node did have a predecessor it is ignored.

For each strategy, we report the results as decrease in time for number of clinics (nodes) merged.
The reason we apply this to cliques the size of 2-3 clinics is purely practical. From an operational perspective it is more practical for 2-3 clinics to cooperate. Moreover the intuition is that the path length a patient travels in the graph is typically around 2-3 as we show from the data. Finally, while it can be argued that merging all clinics would save maximal time , this is not a suggestion we make and is clearly impractical. The results we obtain will need to be filtered in such a way that will make sense clinically and operationally let alone accommodate provider's schedules and clinic locations.
For each strategy we generated a graph of the paths merged. We further examine the graphs of the leading wait time reducing strategies using visuals and degree distribution.

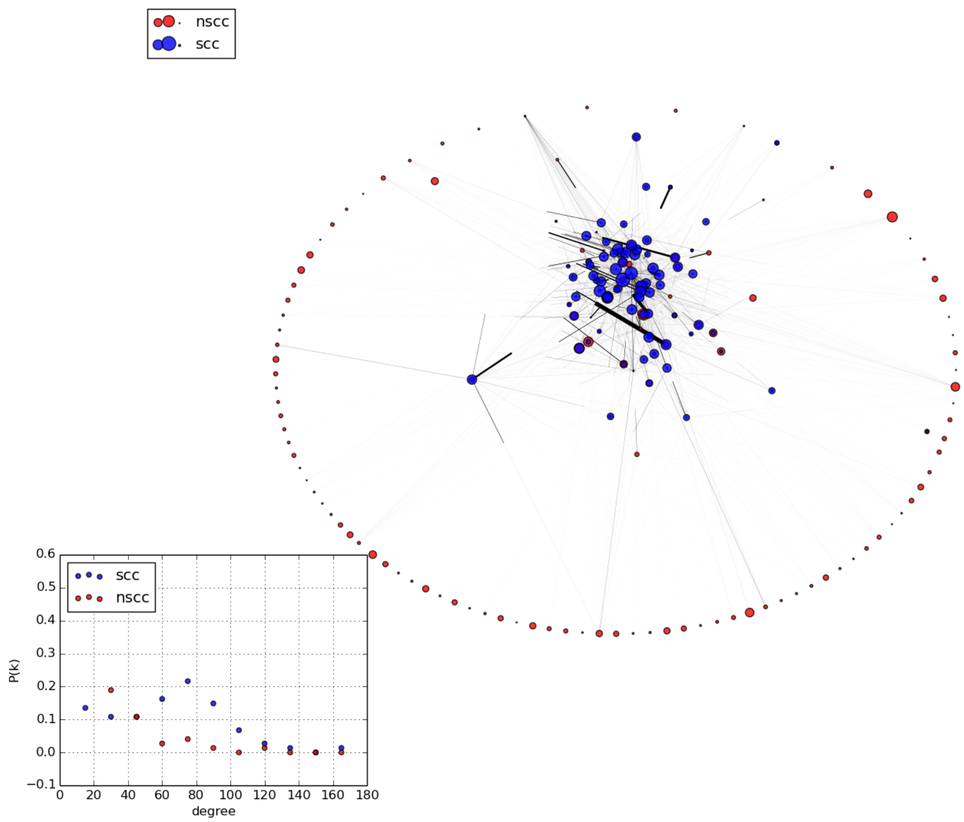

Figure 1: Showing a network of outpatients consultation. Color coded for the non strongly connected component (red) and strongly connected component (blue). Edge width is scaled to $(0-100)$ to reflect that most of the requests are made between nodes in the scc but also reveals traffic between the scc and nscc. Lower left shows the degree distribution.

Results

The data from the VAs outpatient consultation from Washington state were obtained between the years 2014-2015. The set composed of 95,064 edges (consult requests) and 180 nodes (clinics). Analysis revealed a single large strongly connected component (scc) composed of 74 clinics which comprises the clinical services (Fig 1).

The rest of the components compose the auxiliary services (i.e. prosthetics, social work etc.) with very small networks (1-2 clinics). Hence for the sake of analysis all analysis will refer to the strongly connected component (scc) and non strongly connected component (nscc). The average shortest path length is 0.906 and 1.86 for the full graph and scc sub-graph respectively. In figure 1 we also plot the degree distribution for the two components, though given the small number of nodes it is difficult to make an inference about the distribution family. Of note the highest out-degree is from primary care clinics, and the most in-degree is for rehabilitation medicine and physical therapy (both clinics are in the scc as expected).

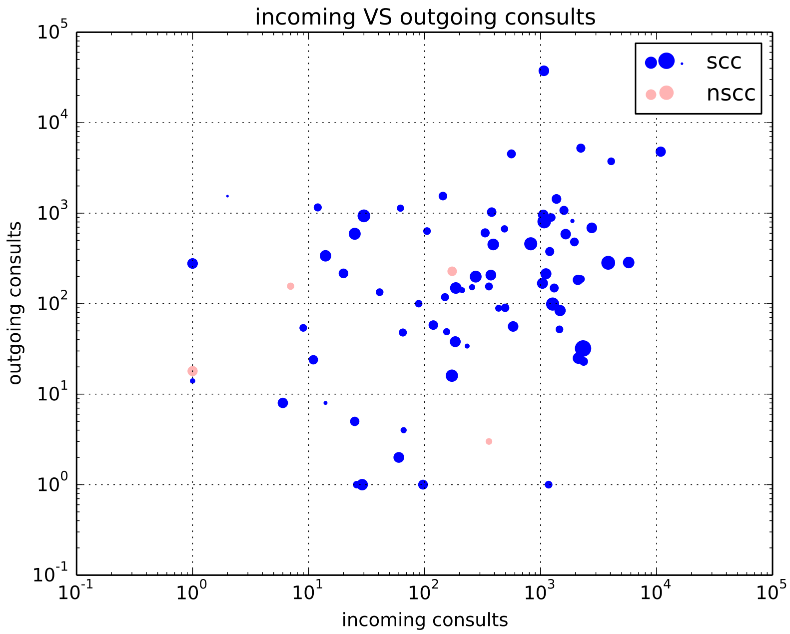

Figure 2: Capturing the in/put flow through clinic. Node size corresponds to processing time. Most traffic occures in the scc subgraph.

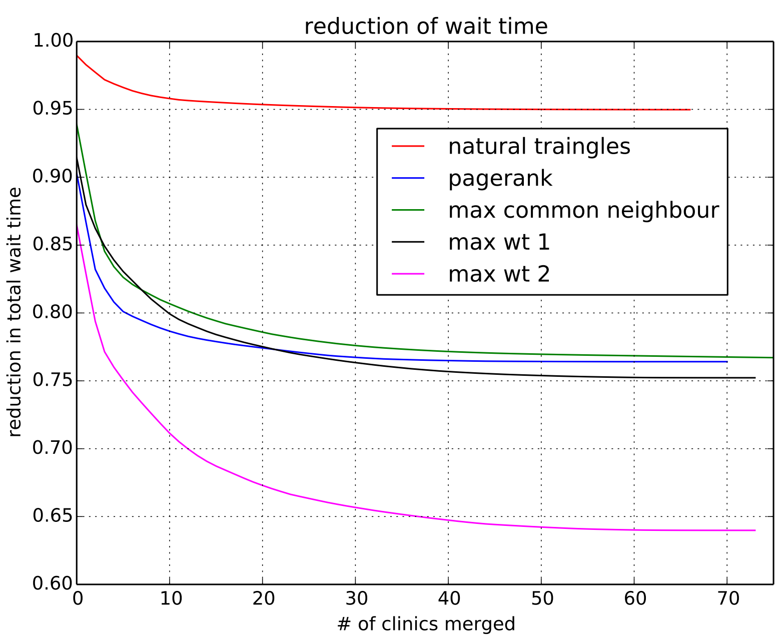

Figure 3: Showing the time reduction in scc using the different strategies.

In figure 2 we capture visually the consultation traffic through a clinic (in/out consultation requests) and the time the clinic processes consultations. We observe again that the bulk of consultation work is carried by the clinical services captured by the clinics which make up the scc. Additionally a handful of auxiliary services which handle a significant amount of requests. Figure 3 details the results of time saved in the strongly connected component for the described models. Merging a node with two other nodes with which it has the highest weighted edges proved to be the superior strategy (model 2).Table 1 shows the 3 leading recommendations for the Pagerank based strategy (model 4) and the and model 2. Of note the recommendations made are quite comparable. A full visualization of the recommendation is given in the recommended clinic network structure that the strategies built in figure 4 (Pagerank) and 5 (model 2). The visualization contain the paths of clinic merging using the said strategies. For each network we plot the degree distribution for that network. In both cases the distribution is skewed suggesting that a handful of clinics concentrates many of the edges.

Discussion

An analysis of a network of outpatient patient consultation showed that the community of care givers in a medical facility is composed of a single strongly connected component composed of all the clinical services and a multitude of other non-clinical services which typically have little contact between them.

We were able to show significant reduction in wait time between 20%-30% by the application of clinic merging. The use of existing triangles between clinics puts to the test the hypothesis that the way clinics are currently set to work today is efficient. Put differently, the use of existing triangles for merging clinics is the case of natural history of outpatient consultation. From the result it is clear that the current way of serving patients falls short in use of time. This is evident by observing that merging triangles along the already existing paths has the worst performance. We noticed that merging two clinics with the longest wait time common neighbour or a merging a node with the maximally weighted node among its neighbours is comparable to merging a node with two other nodes with the highest Pagerank. This is an interesting observation. In the different strategies detailed we use wait time and number of requests were used to select node for merging. Pagerank is a measure of centrality which is solely based on the network topology, still we have evidence suggesting that a generic property of the network can be used to select nodes in a meaningful way to save wait time. The strategy of merging a clinic along its most heavy edges turned out superior. Applying this method to as low as 5 clinics will reduce wait time by 25% across the board. The prominence of physical therapy, vascular surgery, Polytrauma and substance abuse serve to inform us on the issues that Veterans face.

In summary, in this study we undertook a preliminary study of a network of outpatient consultations. We offer suggestions as to how to restructure outpatient consultations in such a way that will foster more cooperation between clinics and save time in servicing patients. We were able to show that the natural way that clinics are organized is not conducive to cooperation. By linking clinics with other clinics using their corresponding Pagerank or weights in the network we were able to construct a topology which may be more conducive to cooperation and to expedient clinical service. The results presented here are an extreme case of efficiency where clinics are really fully merged. In real life one would expect a less pronounced effect. This work did not account for clinics geo-location, availability of services etc., future work will have to address these issue. Since clinic names in the VA are standardized, the method presented above can be used both

	Pagerank	two max weighted common neighbour
	PRIMARY CARE, DENTAL PRIMARY CARE, POLYTRAUMA REHAB, POLYTRAUMA	PRIMARY CARE, REHAB & REHAB REHABILITATION, POLYTRAUMA] DENTAL, EarNoseThroat Surgery]

Table 1: Leading recommended clinics for merging using the Pagerank method and linking to 2 clinics with highest edge weights.

to compare networks of outpatient services across VAs nationwide and make similar suggestions.

References

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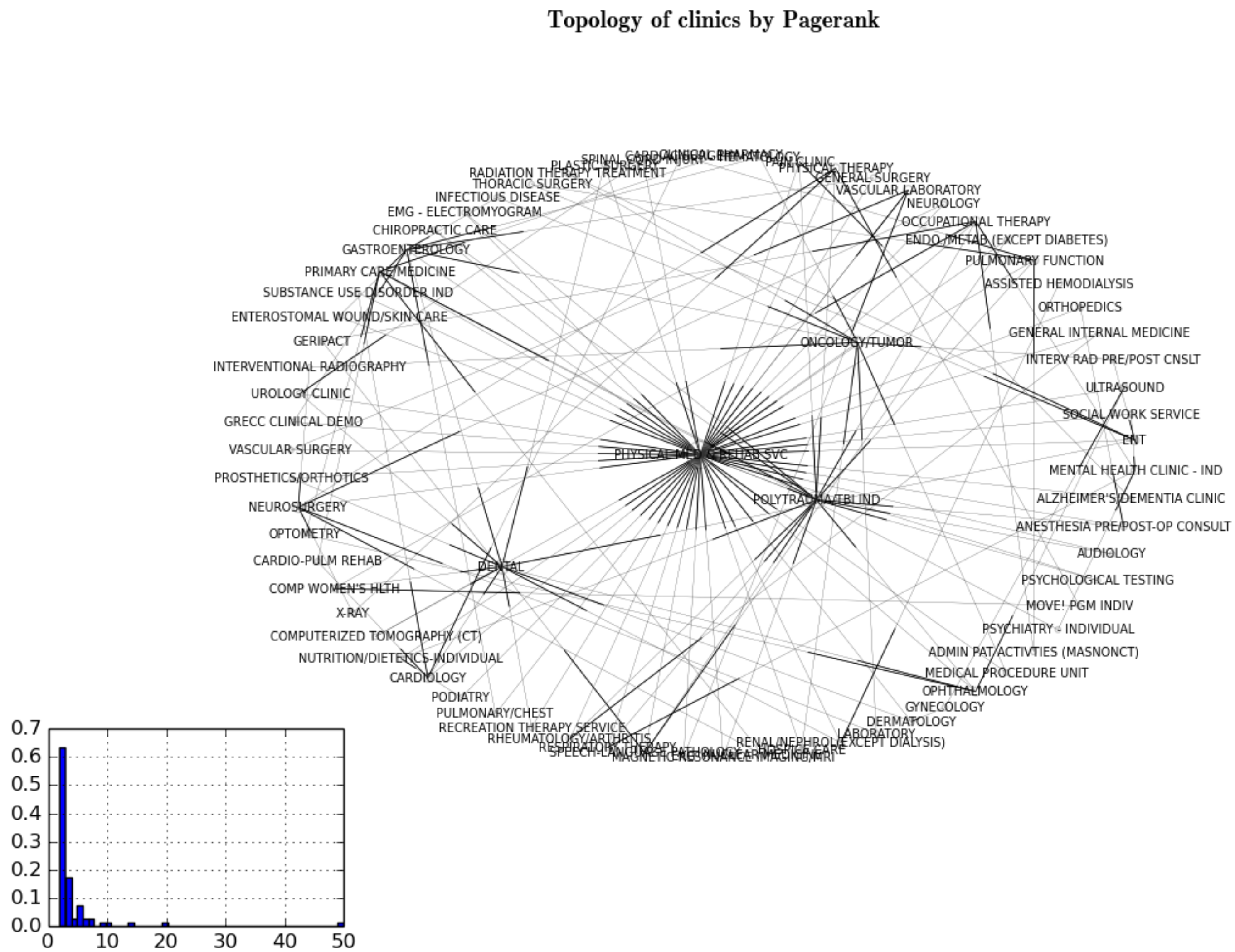

Figure 4: A graphical representation of the clinic organization using method 4. Each edge suggests a pair of clinics that may be merged. We observe several priminent clinics such as physcial therapy, polytraua, dental clinic. Merging those clinics with any of their edges will confer a reduction in wait time.

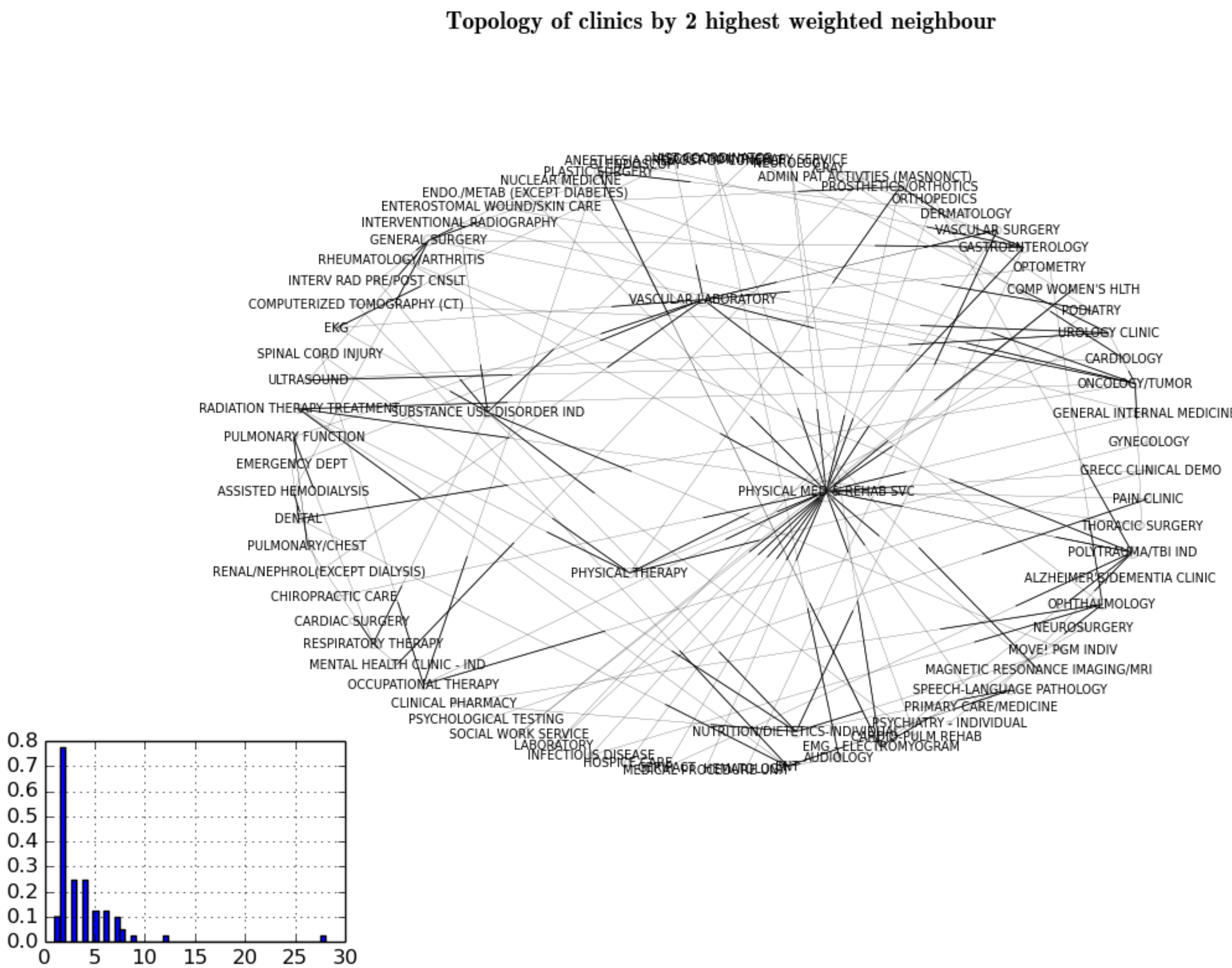

Figure 5: A graphical representation of the clinic organization using method 2, with two neighbor clinics. Each edge suggests a pair of clinics that may be merged. We observe several priminent clinics such as physcial therapy, substance disorder clinic and vascular surgery. Merging clinics along these edges will confer a degree of reduction in wait time.