ORIGINAL ARTICLE

The role of cognitive bandwidth in more cost-effective CT scan usage: A study in reducing "prevention costs"

Ramesh Madhavan[1], Camelia Arsene[2], Sanjeev Sivakumar[3]

1. Wayne State University Physician Group, Detroit, MI, USA. 2. Department of Medicine, Sinai Grace Hospital, Detroit, MI, USA. 3. Department of Neurology, DMC/Wayne State University, Detroit, MI, USA.

Correspondence: Ramesh Madhavan. Address: Associate Chief Medical Officer, Wayne State University Physician Group, Detroit, MI, USA. E-mail: rmadhava@med.wayne.edu

Received: July 3, 2013 **Accepted:** September 16, 2013 **Online Published:** October 11, 2013
DOI: 10.5430/jha.v3n1p55 **URL:** http://dx.doi.org/10.5430/jha.v3n1p55

Abstract

Background: Research has shown preventative care measures aimed at reducing healthcare costs can actually increase them. The objective of this study was to observe the relationship between cognitive capacity and preventative CT scan use relative to best practice.

Methods: Conducted in July 2012, the study involved a retrospective analysis of 825 consecutive head CT examinations performed over one month by ED physicians crossing three shifts in a large Detroit medical center. Military Acuity Model data mining and modeling techniques were used to examine the relationship between CT head yield to order timing in terms of cognitive capacity and decision fatigue relative to health risk reconciliation.

Results: The study showed the number of CT scans ordered increased as physician shifts progressed, while the test value to clinical management decreased. Cognitive capacity was assumed to be at its highest at the start of physician shifts (when Decision Fatigue was lowest); Results indicated physicians were better able to evaluate CT scan use risks and trade-offs. Translating the study results into actual dollar amounts showed an opportunity cost of 26.7%, or more than $43,000 per month, for CT head/brain scan use alone.

Conclusions: Ensuring the management of CT scan usage at the levels of efficiency demonstrated when the study physicians were performing at the level of their In-House Best Practice, is critical to maintaining high levels of patient care at the least possible cost. There is more than $1 million in potential annual cost savings attributable to this phenomenon of cognitive bandwidth affecting radiology decision-making for the average U.S. hospital.

Key words

Cognitive capacity, CT scan, Data mining, Decision fatigue, Healthcare efficiency, Military acuity model, Patient safety, Health care cost

1 Introduction

As the population continues to age, healthcare will remain a leading issue in the United States. It seems everyone has a plan for controlling the growing mountain of expenses, with prevention rather than treatment being the focus. Given interest by the Centers for Medicare & Medicaid Services (CMS), the safety afforded by in-depth testing must be weighed against the costs of the preventative intervention. A 2008 preventative care study showed 80% of measures aimed at reducing expenses actually increased them [1] and another 2008 cardiovascular disease study found prevention would cost almost 10 times as much as it would save [2]. Ultimately, preventative practices can increase the country's healthcare price tag and reduce the number of patients that receive optimal levels of care. The key is to think carefully as to when to apply a preventative action.

To make the right decision on whether or not to use preventative testing, one must look closely at both sides of the equation. For example, using CT and MRI technology in neurological disease diagnosis and patient care has certainly revolutionized the practice of medicine. But, at what cost? In spite of evidence-based guidelines, CT scan use increased from 2.8% to 13.9% over a 12 year period [3], adding thousands in diagnosis expense alone. While the results undoubtedly aid in neurological problem identification and treatment, the incidence of false positive results makes the test even more pricy, such as when it is used in Emergency Department (ED) CT scanning or routine screening mammography [4].

An original research study on the efficacy of preventative CT scan may shed some light on this issue. Conducted in July 2012 involving ED physicians over three shifts in a large U.S. academic medical center, we used ground-breaking data mining and modeling techniques to objectively examine the relationship between CT head yield to order timing. Specifically, the study objective was to observe the relationship between the dimensions of cognitive capacity and the cost-effectiveness of CT use relative to best practice.

2 Method

In approaching the CT head utilization safety and efficiency initiative in our ED clinical practice, we wanted to examine it from a more innovative angle. To this end, we employed a new approach: the Military Acuity Model (MAM). Originally developed for the Air Force Medical Service to fill a void in acuity measurement, MAM is now a joint offering by Lt. Col. Douglas Howard, USAF Ret. and ProcessProxy® Corporation for improving healthcare team cost-effectiveness. MAM was particularly helpful in understanding our study problem of "connecting the dots" on evaluative tasks that were seemingly not being completed when doctors were busy [5, 6].

MAM relies on three key patented methods. The first two methods relate to identifying and exchanging tasks having different values, while the third models the cognitive capacity of healthcare team members in terms of perceived task complexity, multitasking tipping points (where people slow down and make mistakes) [7], and decision fatigue. As cognition is the higher mental process of thought and perception, which includes intellectual activity such as reasoning, and judgment, cognitive capacity then, is the total amount of information the brain is capable of retaining at any particular moment [8]. Decision fatigue is when an individual's brain becomes so taxed, he or she eventually does nothing or exhibits reckless behavior [9]. Decision fatigue is different from physical fatigue; one is not consciously aware of being low on mental energy and thus may intellectually behave in a way he or she might not otherwise, given differences in timing or situation. When physicians are at cognitive capacity limits, including suffering decision fatigue, they may be reluctant to make trade-offs (an advanced form of judgment) in thinking through the complexities involved in head trauma diagnosis and thus may make unwarranted decisions critical to patient care efficiency and effectiveness.

In this respect, while MAM focuses on healthcare cost and efficiency, it really is a patient safety initiative. It has the perspective essentially that if it's too urgent, it's too late. Modeling for acuity helps to predict lead time better, which in turn enables the caregiver to deploy countermeasures to prevent problems better, faster - and cheaper.

Patient safety experts, such as Peter Pronovost, MD, are continuously identifying the high yield tasks [10] for micro-targeting. However, MAM micro-targets resources to do those high yield tasks that, due to cognitive overload, may not otherwise get done. MAM and its Process Arbitrage Method [8] also focus on the cognitive bandwidth needed to perform risk evaluation and reconciliation. It is the use of this data that helps improve the cost-effectiveness of preventive measures.

 ISSN 1927-6990 E-ISSN 1927-7008

Greater cognitive bandwidth is needed for better clinical management and effective task execution. Increased multitasking and decision fatigue causes cognitive bandwidth constriction, which has already been shown in other studies relative to acute care [8] and congestive heart failure [11]. In our study however, the focus was more on how the healthcare team could become better at risk reconciliation - and thus cost-effectiveness - during periods when they were estimated to have more cognitive bandwidth due to less decision fatigue.

We conducted a retrospective analysis of 825 consecutive head CT examinations performed over a one month period in late 2011 in a Detroit metro area teaching hospital where Wayne State University Physician Group has a research affiliation. The scan orders encompassed two staggered shifts. Cases were assessed based on ED physician order time to determine CT value in improving clinical outcomes. This assessment served as the basis for determining whether or not the CT was high yield in patient clinical management. Then, cognitive bandwidth and decision fatigue were estimated from the number of patients being seen relative to the estimated number of physicians available. We hypothesized decision fatigue would increase (along with a correlated cognitive bandwidth decrease) as the shift progressed for each ED physician.

The data collection was limited to patients older than 18 years of age and included scans obtained within first four hours of the admission date. Institutional Review Board (IRB) approval was obtained for the retrospective observational study of de-identified CT head-related patient data. The de-identification included exclusion and scrambling of protected health information and many elements of the protected health information were not accessible to investigators or other key personnel involved in the study. Data collected included CT head order and report times, healthcare staff imaging requests, and the reason for imaging based on the clinical impression.

The MAM tools for unstructured data mining were used for data analysis. Variables parsed using the process mining included registration time, CT order timing, and reason for the scan. Two neurologists reviewed the clinical impression field and confirmed the clinical diagnosis. CT head reports were also reviewed manually for confirmation of the automated report findings. The reports fell into the following categories:

- normal scan
- acute ischemic stroke
- acute hemorrhagic stroke
- ischemic stroke with hemorrhagic conversion
- small vessel disease
- encephalomalacia secondary to an old stroke
- cortical atrophy
- changes secondary to trauma in patients presenting as a trauma code
- subdural hematomas identified in patients not presenting as a trauma code
- tumors
- other abnormalities

One independent investigator compared the reason for the CT head study, clinical impressions, and CT findings. The investigator then listed the yield as positive and changed the clinical management of the patient as needed.

3 Results

Not surprisingly, we found the number of CTs scans ordered increased as the shifts progressed, while their value to clinical management decreased.

As illustrated in Figure 1, the cost of CT use was reflected by the number of CT scans ordered during the one month assessment period. This is the red line. The blue line depicts the percentage of CT scans that positively impacted patient clinical management during the assessment period. As previously stated, our hypothesis was that as the shift progressed, ED physician decision fatigue would increase as cognitive bandwidth decreased. Thus, these two key trend lines would support our hypothesis if: (a) the red line is going up while the blue is coming down, (b) the red line is going up faster than the blue, or (c) the red line is coming down slower than the blue. We included dashed lines to display the interpolation of the points and general slope of the lines.

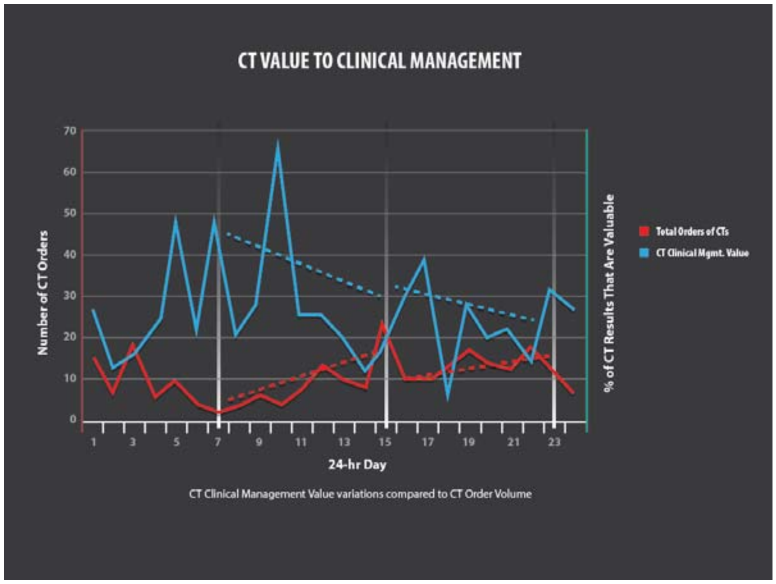

Figure 1. An illustration of the value of CT scans to patient clinical management

The study focus was to estimate potential cost impact from less cost-effective process choices, which in this case was the use of CTs earlier in the patient stay for typically low-yield diagnoses and risk factors, such as headaches or altered mental status. Physicians that were better able to evaluate risks and trade-offs in cost-effectiveness were presumed to be those with more cognitive bandwidth.

Again, not surprisingly the results indicated ED physicians and their teams were able to handle CT scan use more cost-effectively at the beginning of their shifts. We called all the tasks (including the evaluative tasks for risk trade-offs) being done by the entire team during this time period the In-House Best Practice (IHBP) [11], as it was a process that had proven performance for the healthcare team working together “in-house” at the facility.

4 Discussion

As we can see from the results, IHBP was typically when the cognitive bandwidth of the ED physicians and their teams was estimated to be highest. At other hours testing efficiency dropped-seemingly in line with decreases in presumed efficiency of ED team mental processing capacity. What is most notable in the IHBP table, however, is that the number of inconsequential CTs more than doubled over the course of the shift, then essentially reset upon the start of each new shift.

To understand the amount of cognitive capacity available, we examined ED physician staffing. Physicians worked eight hour shifts, but those shifts were staggered. Starting at 7:00 am there were two ED physicians, but by 9:00 am there were four ED physicians. Two new physicians would start their shifts at 3:00 pm as the two 7:00 am ones left, and by 4:30 pm, another two new physicians would have arrived. Finally, two new physicians would replace the 3:00 pm ones by 11:00 pm. No staggered shifts took place after 11:00 pm.

 ISSN 1927-6990 E-ISSN 1927-7008

An intriguing shift time period was 9:00 am. The addition of two ED physicians increased cognitive capacity, which is supported by the spike in yield as illustrated in Figure 1. Also, the 7:00 am and 3:00 pm cost-effectiveness “resets” were noteworthy. Even if ED physicians had varying schedules, an argument could be made that having fresher nurses would help the doctors decrease their decision fatigue, allowing them to use their mental capacity to concentrate on other evaluative tasks, thus perhaps enabling them to connect more dots.

As Figure 2 illustrates, we summarized hourly performance and selected the IHBP for comparison by examining reasonable average volume. This is the reason we chose the afternoon period. Based on the data, we estimated patient volume did *not* correlate significantly with the increasing number of CT scans ordered as the shift progressed. Rather, it was more evenly distributed throughout the day and did not drop significantly at the shift beginning. The CT Count column is not an hourly average, but rather how many CTs ordered fell into the time period under study. To be a true per-hour-per-average day, CT Count would need to be divided by 30. For our purposes CT Count was by hour for the entire month of the study.

FINDING AND VALUING THE IN-HOUSE BEST PRACTICE FOR CT USE

Looking at the Day and Evening shifts show that at average levels of volume, it is possible to get higher yield -- typically earlier in the shift

Approx. Shift	Time (Hour) of Day	Pt. Volume	CT Count	IHBP CT Count	CT Yield	Est. Valuable	Est. Not Valuable	Est. CT Not Valuable Cost* Above IHBP	% Above IHBP	
1	7	5	5	10	20%	1.0	4.0	$ (400)	-33%	
1	8	9	7	10	29%	2.0	5.0	$ (200)	-17%	
1	9	11	6	10	67%	4.0	2.0	$ (800)	-67%	
1	10	14	8	10	25%	2.0	6.0	$ -	0%	
1	11	6	12	10	25%	3.0	9.0	$ 600	50%	
1	12	10	10	10	20%	2.0	8.0	$ 400	33%	
1	13	21	9	10	11%	1.0	8.0	$ 400	33%	
1	14	14	23	10	17%	4.0	19.0	$ 2,600	217%	
2	15	15	10	10	30%	3.0	7.0	$ 200	17%	
2	16	16	10	10	40%	4.0	6.0	$ -	0%	IHBP Selected
2	17	10	13	10	8%	1.0	12.0	$ 1,200	100%	
2	18	21	17	10	29%	5.0	12.0	$ 1,200	100%	
2	19	8	15	10	20%	3.0	12.0	$ 1,200	100%	
2	20	12	14	10	21%	3.0	11.0	$ 1,00	83%	
2	21	12	19	10	16%	3.0	16.0	$ 2,00	167%	
2	22	10	13	10	31%	4.0	9.0	$ 600	50%	
3	23	10	7	10	29%	2.0	5.0	$ (200)	-17%	

Figure 2. A summary of hourly performance relative to the IHBP period selected

The next column, labeled “IHBP CT Count”, assigns a comparison count of CTs ordered, based on the IHBP period that was chosen, which in this case was 4:00 pm. Again, the CT Yield was based on neurologist assessment to determine whether or not the CT scan changed patient clinical management. Thus, a higher CT Yield would be more valuable.

The CT Yield percentage was then used for calculating the data presented in the next two columns on Figure 2. To derive “Est. Valuable” we multiplied the CT Count by the CT Yield to determine how many CT scans would have been valuable in that particular hour in the study period. The column labeled as “Est. Not Valuable” was the flip side, or how many CT scans could be viewed as poor resource use. This was a key number. The less of Est. Not Valuable the better the process efficiency, as it would lower resource utilization while maintaining patient safety and improved outcomes.

Since our goal was to gauge cost-effectiveness by observing the relationship between cognitive capacity and CT use relative to best practice, we needed to translate the study results into actual dollar amounts. To do this, we multiplied the Est. Not Valuable by the estimated cost per CT scan to determine the “Est. Not Valuable Cost Above IHBP.” The possible cost impact related to moving the team toward an IHBP level of performance was based on an estimated [12] CT scan dollar cost. Next, using the lowest average CT scan charges, we focused on the variable costs involved in performing and evaluating the test (*e.g.*, technician time) and on the step variable costs involved in CT equipment purchase and maintenance. Then, any applied overhead that could potentially inflate CT scan charges were excluded and we arrived at a final approximation of $200 per CT scan. The last column in Figure 2 illustrates the percentage the time period was over this IHBP cost.

To highlight the key parameters, findings, and extrapolations of the study, we constructed the table shown in Figure 3.

DETROIT AREA HOSPITAL EXAMPLE: 1 MONTH OF CT ORDERS

CTs ordered within 4 hours of patient admission, that available data showed clearly did or did not impact patient clinical management
Note: IHBP level of non-valuable CTs is baseline, and focusing on squeezing anything above that out

	Pt Volume of pts registered who then went on to get CTs	CT Count	IHBP CT Count	CT Yield	Est. Valuable	Est. Not Valuable	Est. CT Not Valuable Cost* Above IHBP	% Above IHBP
IHBP	12	12	6	40%	4.8	7.2	$ -	
Average:	12.13	11.94	10.00	26%	2.81	9.13	$	26.7% excess costs if use average # of Patients
TOTAL:	194	191	160		45.0	146.0	$ 10,000	

# CT cases w/ data usable for study	265	
# CT cases for month studied	825	or /day = 27.5 so about 1 per hour average
% of cases with CTs sampled	32%	of cases had clean data we could discern the value of the CT more readily, and also were focused on the early CTs that would be done likely by ED doctors. However, we believe other doctors and the remaining CTs have similar opportunities, though they have not yet fully studied
'Fully extrapolated/mo. excess $ =	$ 43,194	$ 518,325 in extra costs annually for CT Head or Brain, which is approximately half of all CTs
(i.e. for all Head or Brain CTs in month, and all hours of ED shifts)		
If can improve 40% toward IHBP =	$ 17,277	$ 207,330 on the EXCESS, not overall (an opportunity we have seen for improvement in Core Measure compliance, reduction in readmissions, etc., using the cognitive load balancing approach), by training via microtargeting, and increasing cognitive bandwidth by load balancing better across HC Team
If other Radiology included (e.g. CTs other than Head/Brain, MRIs, etc.) = ???		
Total est.Cost of CTs for the Month* =	$ 165,000	(1 month in late 2011)
Estimated Savings if Improve to IHBP:	10.5%	

* CT Cost Calculation $ 200
Investment cost (of CT fixed costs of bulb, technician/team, and possibly applied overhead)

Figure 3. A table illustrating the CT scan cost/benefit analysis as compared to the IHBP

As we can see, the opportunity cost (over the baseline IHBP efficiency level) in CT testing is estimated to be 26.7% in excess costs, if the average volume is adjusted to make the IHBP the same as the CTs. The extra cost, when we extrapolate to all CTs in all shifts, would be more than $43,000 per month, which annualized would be well over $500,000. Accordingly, the potential savings, when using a 40% improvement level (demonstrated in other MAM applications), is approximately $207,000 for just CT head /brain scan use in this 300-bed facility ED - and likely double that if all CTs (*e.g.*, chest, gastrointestinal, *etc*.) are addressed using a similar approach.

In short, there is likely more than $1 million per year attributable to this phenomenon of cognitive bandwidth affecting radiology decision-making.

5 Conclusion

During the study we also took the opportunity to examine the impact that moving to the IHBP level of performance could have on overall radiology costs. The percentage (also shown in Figure 3), was determined to be 10.5%. This was the amount, we calculated, that could be reduced by managing CT scan usage to the levels of efficiency proven possible during the times when the team was coordinated well and thinking more clearly - that is, when the team was performing at their IHBP level.

We used a very conservative CT cost ($200) in our calculations. Based on Medicare reimbursement, which is typically near cost, the average CT head scan without contrast for other hospitals in the study area ranged from $250 to $350. Charges to self-pay patients exceeded $1,000. The study did not examine CT scans for chest, abdomen, and other regions. We know these interventions also use contrast materials and consequently, would cost even more than a typical head scan. Other items potentially impacting CT overuse include ED wait delays and radiology bottlenecks. Furthermore, cognitive bandwidth degradation could be affecting other resource utilization, for example the issue of preventable costs and safety.

In summary, this study's findings on radiology resource utilization versus cognitive bandwidth lead to potentially enormous cost savings – without negatively affecting patient care and safety. If cognitive bandwidth effectiveness measures were implemented, a large hospital could achieve CT scan savings from more cost-effective CT use in excess of $2 million per year, or savings to patients exceeding $5 million if patients were to pay for these CTs out-of-pocket.

Dramatically increasing CT cost effectiveness without compromising optimal patient care? Now that should grab everyone's attention.

Permission to use the data

The study was conducted using the hospital data after approval of the WSU and DMC IRB.

Conflict of interest

The author discloses that Wayne State University Physician Group is a member of the ProcessProxy® Healthcare Smartgrid Cooperative, which in the past was partially funded by the US Army's Telemedicine and Advanced Technology Research Center.

Acknowledgements

We thank the project advisor Terry Rajasenan, co-inventor of the Military Acuity Model and Dr. R. Veluswamy, Physician Consultants, Wilkes Barre, PA for their generous advice and support to this research effort.

References

[1] Cohen, J.T., Neumann, Sc.D., Weinstein, M.C. Does preventive care save money? New England Journal of Medicine. 2008; 358(7): 661-663. http://dx.doi.org/10.1056/NEJMp0708558

[2] Kahn, R., Robertson, R.M., Smith, R., Eddy, D. The impact of prevention on reducing the burden of cardiovascular disease. Circulation. 2008; (118)5: 576-585. http://dx.doi.org/10.1161/CIRCULATIONAHA.108.190186

[3] Miller, E.C., Holmes, J.F., Derlet, R.W. Utilizing clinical factors to reduce head CT scan ordering for minor head trauma patients. Journal of Emergency Medicine. 1997; 15(4): 453-457. http://dx.doi.org/10.1016/S0736-4679(97)00071-1

[4] Kerlikowske, K., Zhu, W., Hubbard, R.A., Geller, B., Dittus, K., Braithwaite, D., *et al*. Outcomes of screening mammography by frequency, breast density, and postmenopausal hormone therapy. JAMA Internal Medicine. 2013; 173(9): 807-816. http://dx.doi.org/10.1001/jamainternmed.2013.307

[5] Westbrook JI, Coiera E, Dunsmuir WT, Brown BM, Kelk N, Paoloni R, *et al*. The impact of interruptions on clinical task completion. Qual Saf Health Care. 2010; Aug; 19(4): 284-9. PMid: 20463369. http://dx.doi.org/10.1136/qshc.2009.039255

[6] Magrabi F, Li SY, Day RO, Coiera E. Errors and electronic prescribing: a controlled laboratory study to examine task complexity and interruption effects. J Am Med Inform Assoc. 2010 Sep-Oct; 17(5): 575-83. PMid: 20819867. http://dx.doi.org/10.1136/jamia.2009.001719

[7] Charron S, Koechlin E. Divided representation of concurrent goals in the human frontal lobes. Science. 2010; Apr 16; 328(5976): 360-3. PMid: 20395509. http://dx.doi.org/10.1126/science.1183614

[8] Brennan, J.A., Malaspina, M., Veluswamy, R. (2012, September). A physician partnership: Employing predictive modeling and workload analysis for CHF performance improvement. Available from: http://net.acpe.org/services/2012/Update/09-20/story-1.htm

[9] Tierney, J. (2011). Do you suffer from decision fatigue? Available from: http://www.nytimes.com/2011/08/21/magazine/do-you-suffer-from-decision-fatigue.html?pagewanted=all

[10] Pronovost, P., Needham, D., Berenholtz, S., Sinopoli, D., Chu, H., Cosgrove, S., *et al*. An intervention to decrease catheter-related bloodstream infections in the ICU. New England Journal of Medicine. 2006; 355: 2725-2732. http://dx.doi.org/10.1056/NEJMoa061115

[11] Veluswamy, R. Golden nuggets: Clinical quality data mining in acute care. The Journal of the Physician Executive. 2008; 34(3): 48-53.

[12] Roy, A. (2012). Why do hospitals charge $4,423 for $250 CT scans? Blame Arizona Republicans. Forbes. Available from: http://www.forbes.com/sites/aroy/2012/05/27/why-do-hospitals-charge-4423-for-250-ct-scans-blame-arizona-republicans/