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# The Green Light SONATA: Foundations for Musical Agents Controlling Traffic Signals*

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*Abstract*— **The goal of this research is to improve signal operation and reduce delay through an innovative transdisciplinary integration of traffic signal control and music theories. The main hypothesis in this research is that "the underlying sense that musicians exhibit during improvisation can be utilized to better synchronize signal control with internal traffic rhythm." In this work, we developed and used a SONATA interface to control a simulated traffic signal. It was found that two of the three musicians in this study have outperformed the Webster's optimal control (by 22.3% and 17.6%). It was also found that all three musicians controlled the traffic signal better when they were not looking at the simulation (i.e., using only auditory sensing).**

## I. Introduction

The Texas Transportation Institute (TTI) Urban Mobility Scorecard of 2015 collected and analyzed data from 471 urban areas in the US. The data indicated that there is an equivalent of *$160 billion of wasted time and fuel in 2014 alone* [1]. One of the remedial strategies recommended by TTI is "adding capacity of all kinds." This can be achieved by optimal allocation of traffic signal green times. There is a large room for improvement in what we do in signal control, both in theory and applications, as evidenced by the statistics mentioned above.

### A. Traffic Control Methods

State-of-the-art traffic controllers use physical vehicle sensing information to regulate vehicle movements with control algorithms using three control parameters: cycle, splits, and offsets. Signal cycle optimization has been cited as an NP-Complete problem [2], and offset optimization/signal coordination as NP-hard on arterials [3] and networks [4, 5], which reduces the optimality of current control paradigm. The systems become more complex when we consider a road network instead of a single road link. Two widely used responsive control systems are SCOOT [6, 7] and SCATS [8]. SCOOT implements a gradient descent algorithm with online detector data, while the optimization process with SCATS is done offline to generate candidate signal plans.

Traffic Responsive Plan Selection (TRPS) is a technique that has been embedded in most of the traffic controllers in the US. Abbas et al. used pattern recognition techniques to guide optimal and robust configuration of TRPS [9–11]. Further studies on TRPS followed this track and implemented different machine learning techniques for pattern recognition [12–14].

Another approach to traffic optimal control is dynamic programming (e.g., [15][16, 17][18]). However, the "curse of dimensionality" prevents the dynamic-programming-based adaptive traffic control system from practically being implemented for a large network. There are also controllers implementing machine learning techniques such as fuzzy logic controllers [19–21] and reinforcement learning based controllers [21–24].

### B. Problem Statement

Most, if not all, of the existing traffic control methods utilize central optimization of intersection traffic movements, and can quickly reach the computational capacity of a local (at an intersection) or a master (network-operating) controller. Because of the difficulty/infeasibility of optimizing traffic operation of networks or large corridors, several researchers and operators turned to heuristic methods (e.g., using supervised learning in artificial intelligence, AI). However, supervised learning needs a set of optimized output that corresponds to each input in the training set, which defies the purpose of using AI methods when the optimized output is not known to start with (unless the objective of using AI is to speed up the computation, rather than to improve operation).

Unlike driving behavior modeling, for example, where the change in driver acceleration in every time step is guided by a human choice, the optimality of a given control policy in traffic signal operation is only guided by the final outcome (was the timing plan optimal? What is the total delay at the end of a given time period as a result of following a pre-determined timing plan?). The major missing component in optimal adaptive control of intersection or network traffic, therefore, is the "sense" of correct control actions in each time step. Without this sense, depending on a pre-defined model of delay can quickly become intractable; similarly, depending on a rolling-horizon dynamic programming can suffer from the curse of dimensionality.

## II. Innovative Concepts

In order to address the limitation of existing control optimization methods, we propose a novel and foundationally transformative control paradigm where each control action is guided by a "sense of correctness" obtained from the music domain. The goal of this research is to improve signal operation and reduce delay through an innovative transdisciplinary integration of traffic signal control and music theories. The

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main hypothesis in this research is that "the underlying sense that musicians exhibit during improvisation can be utilized to better synchronize signal control with internal traffic rhythm."

### A. *Music and Control*

Traffic signal control is typically achieved through allocating different green durations to different traffic movements (four through movements and four protected left movements). Previous research showed that it is unlikely to achieve global optimal operation using any closed-form control optimization solution. Engineers typically use some heuristic methods in conjunction with stochastic traffic simulation packages (e.g., VISSIM) to come up with close-to-optimal operation that minimizes an objective function (typically overall delay). VISSIM provides a phase allocation sequence (a phase diagram) for any running control strategy along with the corresponding overall delay at the end of the simulation run.

Looking closely at Figure 1 and Figure 2 below, one can see the resemblance between the phase diagram and the musical score Piano key representation. This realization is what opens the door for potentially very intriguing and interesting research tasks as will be described next.

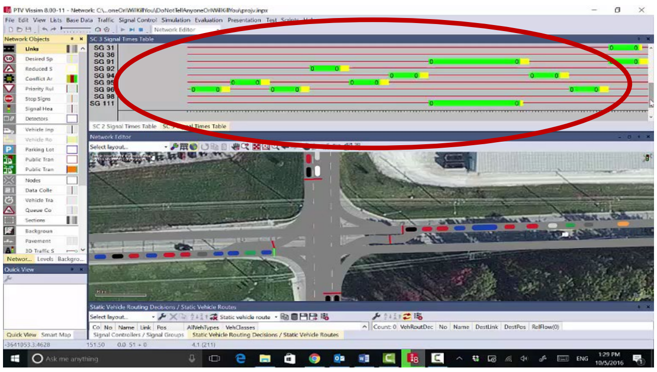

Figure 1. VISSIM traffic simulation with phase diagram

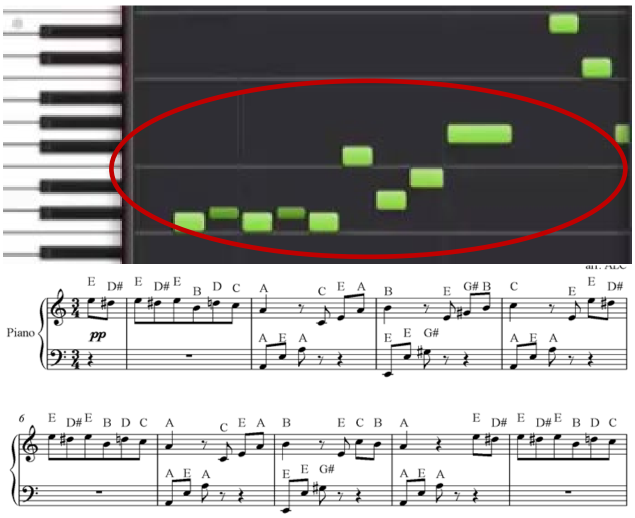


Figure 2. Fur Elise music score with piano representation

### B. *Intellectual Merits*

The work proposed here is the very first research effort bridging traffic signal system control and music theory. The presented work converts traffic arrival patterns at signalized intersections into musical tunes, allowing skilled musicians to listen and play along, while controlling the signal indications in the process. Data collected during this experiment is used to develop a new adaptive controller that would work in the absence of music (the intention is to encapsulate the musician's behavior in a traffic control software agent, and not to lock musicians inside traffic cabinets). The technological innovation includes the development of software system that: (1) extracts and plays traffic rhythms/tunes from microscopic traffic simulations, (2) captures and records musician corresponding tunes, and (3) converts musician tunes into signal indications in the traffic simulation software.

The intellectual merit includes: (1) investigation, analysis and encapsulation of human's capabilities to create optimal control through the musical sense and (2) the creation of an innovative central and distributed control platform that adapts to evolving traffic.

### C. *Paper's Contribution*

This paper presents our foundational work with the following contributions: (1) developing software interface between commercial traffic simulation software and music devices, (2) designing and conducting an experiment to record the actions of musicians who are skilled in improvisation playing in response to different traffic rhythms, and (3) conducting statistical data analyses of musical and signal control performance data. This paper lays the foundations for a transformative transdisciplinary integration of traffic signal control and interactive musical improvisation.

## III. Methodology

Three research tasks were conducted and presented in this paper: (1) development of software and hardware interface between the traffic simulation package (VISSIM) and the acoustic kit (microphone/speakers and associated drivers), (2) designing and conducting an experiment to record skilled musicians playing in response to traffic rhythms, (3) statistical analysis of signal performance when operated by musical improvisation versus traditional control.

### A. *The SONATA Platform*

We developed a software package with a graphical user interface (GUI) and an Application Programming Interface (API) to communicate with the VISSIM simulation software and the Musical Instrument Digital Interface (MIDI) devices. The Green Light SONATA (Green Light Signal Operation with Neuro-fuzzy Acoustic Tuning Application) platform is intended at this stage to provide the communication and data collection functionalities required for this phase of the research, but is intended to be used in the future as a stand-alone neuro-fuzzy control agent. The software package includes an algorithm that maps each detector activation (shown as the blue lines in Figure 3), and the MIDI output (rhythm beats or melodies, depending on a user setting). An algorithm also maps the notes played by each musician into phase indications (shown as the green lines in Figure 3). All data is stored in two separate databases: (1) a VISSIM database, storing all vehicle, signal, and delay data, and (2) a musical notation database, storing all the MIDI data. A module developed in the MAX music software is used to: (1) convert detector actuation into musical notes and (2) convert musical improvisation into VISSIM signal indications.

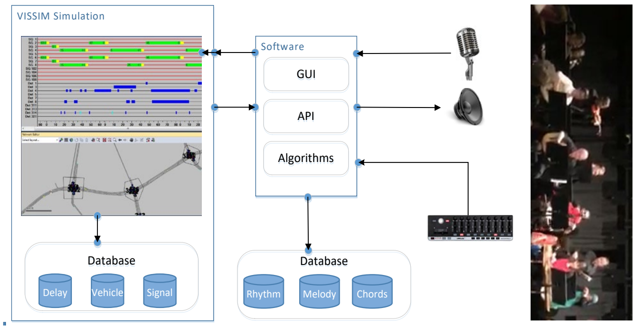


Figure 3. Main Software and Research Framework.

*B. Experimental Setup and Data Collection*

"Improvisation" refers to a wide variety of musical practices, within and across musical styles/cultures. Some improvisation is governed by explicit conventions of playing over a harmonic/rhythmic structure (for example 12-bar blues), whereas other improvisation adheres to conventions that are not made explicit, but simply absorbed in the process of learning a musical system (such as Indian ragas, or Persian radif). We designed an experiment to test the main research hypothesis. Experiment variables included different traffic patterns (changing traffic intensity and variance), using visual and auditory versus auditory only information, and controlling the signal by different musician improvisation styles (Co-authors Abbas, Nichols, and Thomas were the musicians in this research). SAS JMP software was used to analyze data obtained from the experiment. The response variable and surface were built based on the resulting traffic delay of each run.

The experiment was conducted at the DISIS Studio at Virginia Tech where Abbas, Nichols, and Thomas (pictured from left to right in Figure 4 below) performed in response to the sonification of traffic, having their musical performance translated in real-time into signal indication in the VISSIM simulation environment using COM interface and Max software.

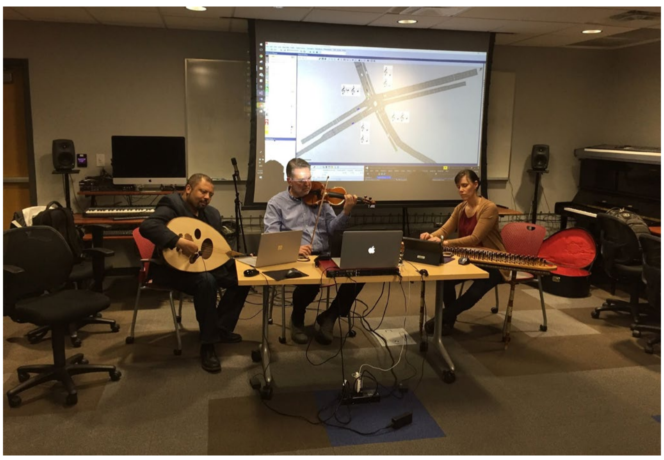

Figure 4. The SONATA Experiment

Each musician performed with and without looking at the simulation. Each detector hit was sonified with a plucked string sound and each detector occupancy (percent of time the detector is on) was sonified with a bowed string sound. Detector information was sonified as a pitch corresponding to the associated National Electrical Manufacturers Association (NEMA) phasing shown in Figure 5. Musicians' play, in response, was converted into VISSIM phase indication associated with the played note. Control parameters corresponding to Webster's optimal control were also coded in VISSIM and the simulation results were compared side to side. Webster minimum delay cycle was computed with equation (1) below.

$$C_o = \frac{1.5*L+5}{1-\sum v/s} \quad (1)$$

Where:

Co: Webster minimum delay cycle length

L: total lost time in each cycle (5 seconds per NEMA phase per ring)

V: critical approach volume

S: saturation flow rate

The phase duration is determined based on the Webster cycle length and the v/s ration as follows:

$$g_i = \frac{\frac{v_i}{s_i}}{\sum \frac{v}{s}} \quad (2)$$

Where:

Gi: green duration for phase i

Other variables as previously defined

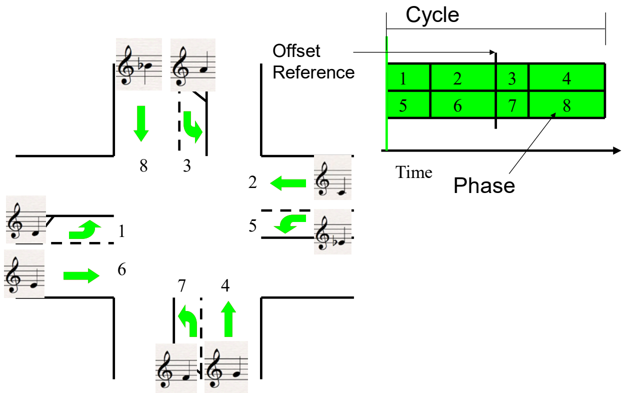


Figure 5. NEMA Phasing and Associated Notes

## IV. RESULTS

All collected data was analyzed using JMP software. The optimality level of musical plays (as compared to a base line Webster control) was used to label each musical control episode. Next, a Markov state transitioning analysis was conducted to analyze and investigate the reasons resulted in that control performance.

## A. *Control Performance—delay*

It was very interesting to find that all three musicians controlled the traffic signal better when they were not looking at the simulation (i.e., using only auditory sensing) as shown in Figure 6. Figure 6 also shows the delay associated with each of the eight NEMA phases, highlighting phases where musicians served better than others. It was also exciting to see that two of the three musicians have outperformed the Webster's optimal control (by 22.3% and 17.6%) as shown in Figure 7. These results are very encouraging and warrants further investigation of the proposed concept.

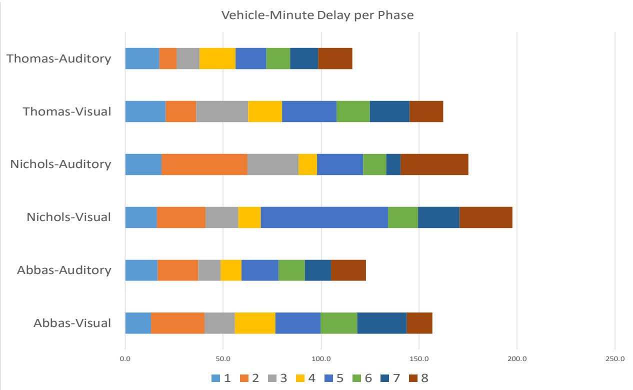


Figure 6. Phase delay corresponding to Musicians' control with visual and auditory

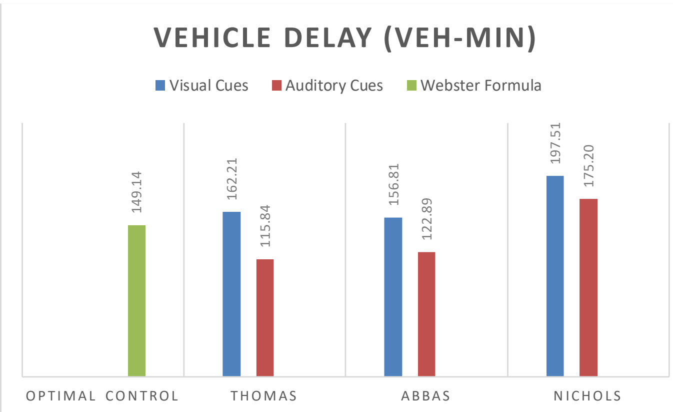


Figure 7. Overall musicians' intersection delay compared to Webster optimal control

Figure 8 shows the statistical t-test analysis of the performers operation. The figure shows that two musicians performances were statistically significant from the rest of performances when they were using auditory cues. This result suggest that there is a value in using all phases harmonic auditory sensing when controlling traffic.

| Level | | | Least Sq Mean |
|---|---|---|---|
| [Charles]Visual | A | | 197.51088 |
| [Charles]Auditory | A | B | 175.20281 |
| [Anne Elise]Visual | A | B | 162.21170 |
| [Monty]Visual | A | B | 156.80570 |
| [Webster]Default | A | B | 149.13538 |
| [Monty]Auditory | | B | 122.88828 |
| [Anne Elise]Auditory | | B | 115.84062 |

Levels not connected by same letter are significantly different.

Figure 8. Statistical significance of musical performance

## A. *Control Harmony*

What we mean by control harmony is how "in-tune" was the musician to the traffic state progression while "improvising" back to control the traffic. Was the musician responding to all phases equally? Was the musician responding to changes in traffic states in real-time such that delay distribution among phases remain the same as time passes by?

These concepts are illustrated in Figure 9 through Figure 14. The figures show the cumulative delay per control period and for each of the eight NEMA phases. For example, the figures show that with auditory cues, Thomas was able to respond better to phases 4, 7, and 6. Her auditory cues were resulting in lesser delay to these phases (than the visual cues control) early on, and then keeping their delay in check. In essence, it seemed that her auditory cues control took advantage of the opportunity to reduce delay for those phases as soon as possible, followed by keeping the delay for those phases in check for the rest of the simulation.

Nichols auditory cues control resulted in a much better attention to phase 8 in comparison to the visual cues control. Another interesting observation is how Nichols built a sequential "pressure" for phases 5, 6, and 7, respectively before coming back and "resolving" that pressure keeping their delay in check from his response point to the end of the simulation. This seems to be the opposite strategy to what Thomas did. It should be noted that Nichols was also attempting to produce "beautiful" pieces of music while responding to the traffic demand, which can lead to the exploration of the relationship between control efficiency and "beauty," which is currently beyond the scope of this paper.

Abbas's auditory responses resulted in a much less variance in his responses to phases (all phases delays are contained within a tight band). His auditory cues control lead to a more equitable control to phase 4 than his visual cues control.

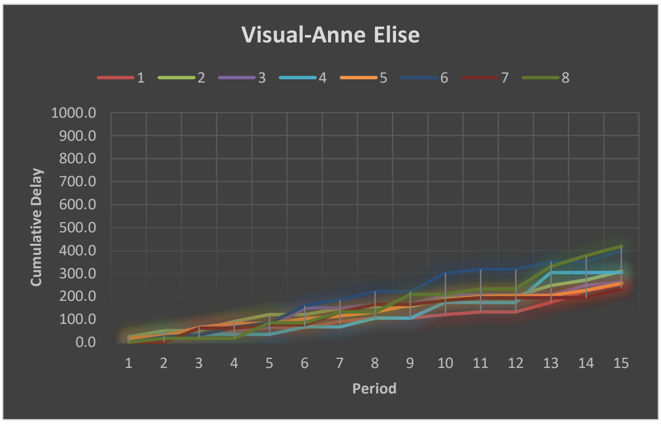


Figure 9. Control harmony-visual cues- Thomas

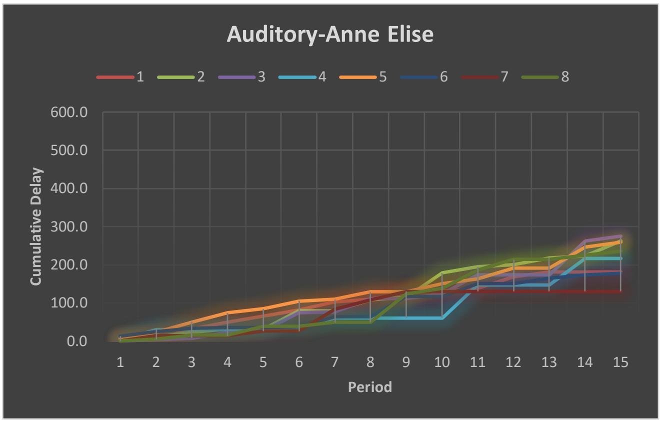


Figure 10. Control harmony-auditory cues- Thomas

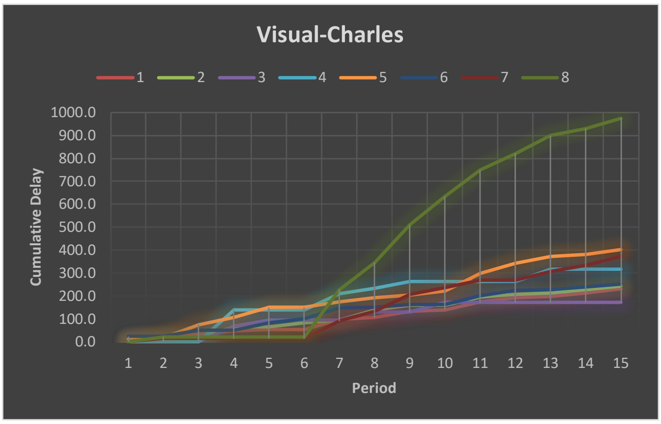


Figure 11. Control harmony-visual cues- Nichols

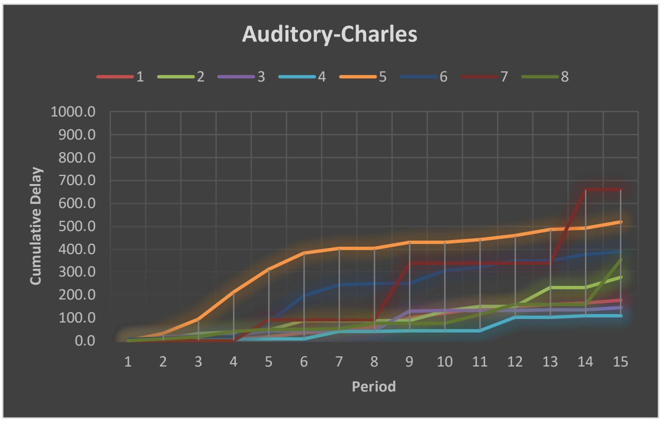


Figure 12. Control harmony-auditory cues- Nichols

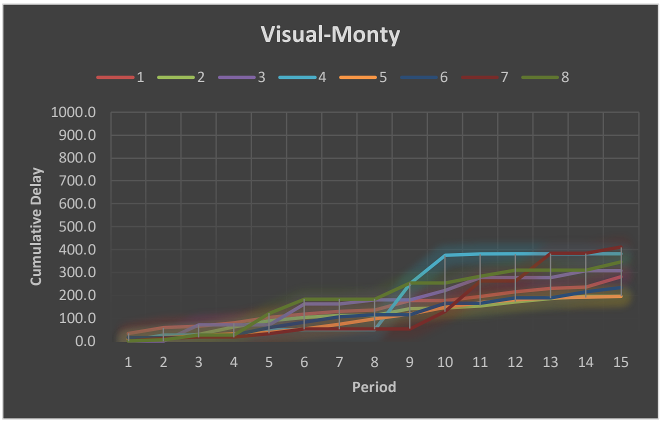


Figure 13. Control harmony-visual cues- Abbas

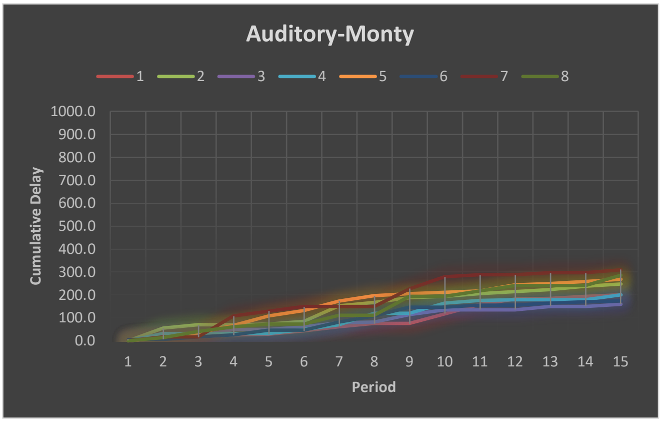


Figure 14. Control harmony-auditory cues- Abbas

### *Phase Transitions*

We also analyzed the transition probabilities from existing phases and the action that each musician took (sending a particular phase invocation signal). The y-axis in Figure 15 shows the phase that was last invoked, and the legend color shows the phase that was invoked by the musician at each time step. The figure shows, for instance, that Nichols stayed in phase 8 significantly longer than Thomas and Abbas; Abbas stayed the least in phase 6 than the other two participants. Thomas hardly remained in phase 2, etc. Insights obtained from this figure will be used in future work to develop encapsulating control agents.

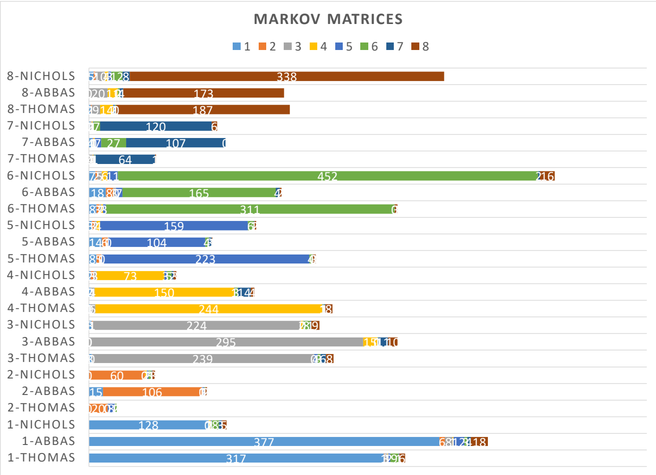


Figure 15. Phase transitioning

## V. Conclusions

In this paper, we presented the very first attempt at controlling traffic signals based on musicians intuitions and ability to improvise. The platform presented here (the Green Light SONATA) sonifies traffic data and converts musicians improvising responses into signal indications. Our preliminary results shows that two out of the three co-authors were able to beat Webster optimal control using auditory signal information only. We also discussed the impact of the different improvisation styles we implemented on signal performance. These findings are very encouraging and warrant further investigation and development.

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