A Multi-Agent System for Modelling Urban Transport Infrastructure Using Intelligent Traffic Forecasts

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Abstract. This paper describes an integrated approach for modeling transport infrastructure and optimising transport in urban areas. It combines the benefits of a multi-agent system, real time traffic information, and traffic forecasts to reduce carbon-dioxide emissions and offer flexible intermodal commuting solutions. In this distributed approach, segments of different modes of transport (e.g. roads, bus/tram routes, bicycle routes, pedestrian paths) are simulated by intelligent transport agents to create a rich multi-layer transport network. Moreover, a user agent enables direct interaction between commuters' mobile devices and the multi-agent system to submit journey requests. The approach capitalises on real-time traffic updates and historical travel patterns, such as CO_2 emissions, vehicles' average speed, and traffic flow, detected from various traffic data sources, and future forecasts of commuting behaviour delivered via a traffic radar to calculate intermodal route solutions whilst considering commuter preferences.

Keywords: Multi-agent system, traffic forecasts, transport infrastructure, path finding, dijkstra algorithm, A* algorithm, intermodal route guidance.

1 Introduction

The transport sector is the second biggest source of greenhouse gas emissions after the energy sector in Europe. It is responsible for approximately 20% of overall greenhouse gas emissions in Europe, with more than two-thirds of that being released from passenger cars. Moreover, CO2 emissions of transport have increased by 23% between 1990 and 2010 [1] despite the introduction of energy-efficient vehicles. To achieve sustainability in transport, there is a pressing need to manage and optimize transport, especially road transport, in a more efficient manner by reducing road congestions and idling times of vehicles, and by offering commuters more eco-friendly forms of commuting such as buses and trams.

Recent research efforts in the field of transportation have focused on optimizing urban traffic and reducing traffic congestion using agent-based computing [7] owing to its distributed nature and ability to deal with uncertainty in an environment [3].

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Examples include the TRACK-R platform [5] which recommends route solutions using travel time as the cost between any two nodes. TRYSA [6] is another example of a decentralised multi-agent platform for reducing congestion in motorways where agents simulate sections of the motorway. However, none of these efforts aimed at reducing congestion by using a multitude of actual indicators such as CO_2 emissions and vehicles' average speed, and enabling multimodal coordination and cooperation through a multi-modal agent system.

To optimise the management of urban transport, we propose the use of software agents which act as self-organising and self-steering entities to simulate transport infrastructure and traffic conditions and find alternative intermodal commuting routes that satisfy the preferences and requirements of commuters as well as to reduce carbon dioxide emissions. The model proposed herein contributes by, firstly, accounting for several traffic-related variables including ***estimated carbon-dioxide emissions, real-time traffic flows, vehicles average speed, and intelligent traffic forecasts***, and secondly, suggesting ***intermodal route recommendations*** that fit user preferences and demands. The traffic forecasts are generated by a traffic radar which is based on the PROSA [26] and Delegate multi agent architectures [27].

The remaining of this paper is organized as follows. Section two reviews the related literature about traffic management and simulation. Section three proposes our multi-agent traffic management system and details its architecture. Section four discusses the implications of the multi-agent system in respect to managing urban traffic. Finally, section five outlines a future research plan for testing the multi-agent system.

2 Related Work

The transport domain deals mainly with people moving from one place to another in an urban environment. This domain is commonly seen as dynamic because of all the players and their interactions involved in it, for instance private cars, buses, trains and underground among others. Additionally, there is the infrastructure to consider: streets and sensors underneath, traffic lights, and (electronic) signs. Typically, the need for transport is called demand and involves the flow of vehicles, pedestrians and freight, and the transport offer is called supply which involves the infrastructure and services [16].

The fluctuations in the transport demand during a period of time, unexpected accidents and faults, delays, energy consumption, and a limited transport supply make this domain increasingly complex and calls for the need of approaches to distribute the demand within the infrastructure and optimise its usage [16]. Existing approaches focus on diverse and specific aspects of transport, for instance on traffic coordination at traffic management centres, cf. [17], maximisation of (urban) network throughput by controlling the signalling at adjacent road intersections, cf. [18], or improvement of the traffic flow by optimising both the timing of traffic lights and routes selected by drivers, cf. [16]. Even when some approaches have shown improvements, there is still work to do especially to support the ability of incorporating and adapting from sudden transport changes, cf. uncertainty [8].

Software agents and multi-agent systems [15] are increasingly being used to solve overarching issues in the domain of traffic and transportation systems, namely traffic congestions, vehicle emissions, and transportation coordination. The applications of agent computing paradigm ranged from modeling and simulating traffic, managing congestion, and dynamic routing and recommendations [8]. Urban traffic control strategies to reduce traffic jams include intersection signal control [9], bus fleet management [10], integration of urban traffic control and route guidance [12], and intelligent route guidance [11].

Agent-based platforms for road traffic management include TRACK-R for route guidance [5], MAS incident manager for incident management [19], Mobile-C for uncertainty handling [20], and aDAPTS [21] for traffic congestion management. These platforms use agents to model the behavior of vehicles, signal lights, and road segments. Other research efforts focused on modeling the behaviour and reactions of drivers, e.g. upon receiving traffic updates and news [22]. Agent simulation is also applied to the management of bus networks by modeling buses operation and travelers behaviours [23]. The movement of pedestrians in urban environments has also been modeled to help evaluate the effect of infrastructural changes on walking patterns [24]. The majority of these agent-based architectures model only a single mode of transport and do not account for the diverse needs of commuters, nor do they explicitly target transport carbon-dioxide emissions. However, our architecture endeavours to fulfill this gap by simulating all common modes of transport in urban areas, relying on real time traffic data and traffic forecasts, to create a richer and multi-layer transport network that is capable of devising flexible route guidance.

3 A Multi-Agent System for Optimising Transport Using Traffic Forecasts

3.1 Overview of the Multi-Agent System

The agent-based model aims to simulate the transport infrastructure and help end users find appropriate routes for their travel requests, where a travel request contains an origin and a destination. An intelligent agent-based traffic management model should have knowledge about the current status of transport at any time and be able to devise suitable optimizing strategies accordingly. The model we are proposing is advantageous in several ways. For instance, it addresses the issue of multi-modality by covering and combining four modes of transport. In this respect software agents simulate road segments, public transport segments, cycling routes and pedestrian paths (see Fig. 1). Physical properties of such infrastructure are collected from urban and traffic management and control centres (for the cities of Nottingham, UK and Sofia, Bulgaria) and delivered to the multi agent system. Another important functionality of the multi agent system is the calculation of the cost of segments which is then used to find the most environment-friendly routes for a particular user. Cost of each segment is determined through a number of real time variables such as average speed of cars, CO2 emissions for a particular road segment, traffic flow, bus/tram reservations, and travel patterns. These variables are collected and processed separately by the traffic data sensors and SCOOT system [2] of the UTMC centres and updated on a regular basis (e.g. every 2 minutes). Other static information of segments are also taken into account (e.g. physical length of segments, number of lanes, and capacity of public transport).

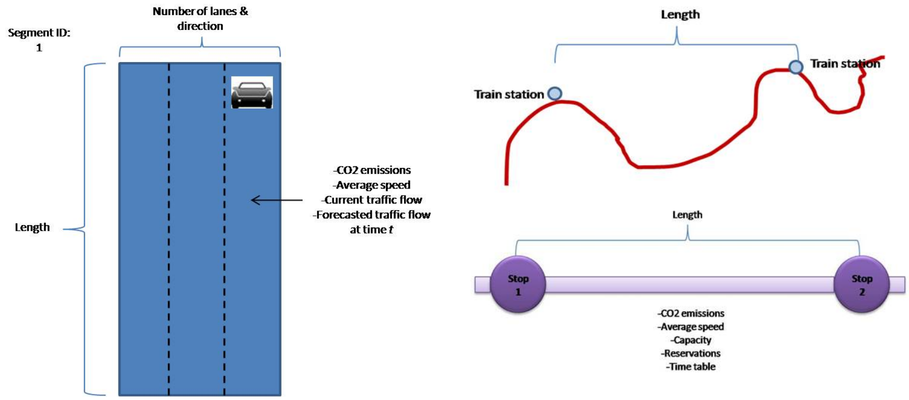

Fig. 1. Road Segment (left), Cycling Segment (top right), & Tram/Bus Segment (bottom right)

Characteristics of our multi-agent system include:

- **Intermodal:** covers a variety of modes of transport, thus accommodating the needs of various types of commuters.
- **Communicates with the commuter:** the multi-agent system receives user journey requests and provides route solutions that satisfy user preferences (e.g. time of travel).
- **Capitalises on a wide range of data sources**, varying from physical properties, real time data, and historic data. These data come from actual traffic management control centres.
- **Simulates a real world problem:** road transport contributes to 20% of the pollution and CO_2 emissions in Europe [1], and is distributed geographically and highly dynamic.
- **Uses real-time data:** agents receive real-time information about traffic from urban traffic control centres and available traffic sensors (e.g. SCOOT data [2]). This enables the agents to recognise the load of the transport network and any traffic problems.
- **Distributes traffic information**: agents communicate their costs to neighbouring agents, thus propagate traffic information throughout the transport network.
- **Exploits traffic forecasts**: our model extends existing models by exploiting forecasts about the situation of traffic in the future via the traffic radar.

3.2 Architecture of the Multi-Agent System

The proposed multi-agent system for providing route guidance contains an environment and a number of intelligent agents living in the environment. We chose to use the AGLOBE framework [4] to design and implement the multi-agent system. Our choice of this agent framework is motivated by the efficiency of message communication and lightweight nature of the framework. The founders of AGLOBE performed a number of benchmark tests against rival agent development platforms JADE, ZEUS, FIPA OS, and JACK and showed the superiority of AGLOBE over these frameworks [4]. Other benefits of using AGLOBE include the ability to simulate real-world problems and collaborative communities, increase the number of autonomous agents in the environment, and flexibility migrate between different containers and platforms.

The components of our multi-agent system were devised depending on the flow of information to and from the commuter on the one hand, and from and to the urban transport centre data sources on the other hand. In principle, a commuter would submit a journey request via a mobile device. The request along with other relevant commuter preferences, such as available modes of transport and preferred time of travel, are collected by a user agent of the multi-agent system. Therefore, the user agent enables the interaction between commuters and our multi agent system, and communicates journey requests to the managing agent, which coordinates and manages the actions of all agents (e.g. sensor agent and transport agents). Information about the transport infrastructure and situation of traffic is collected from available urban traffic management centers using a sensor agent. This information include static properties of transport infrastructure which are requested once at the start of the simulation, such as length of road and public transport segments, number of lanes per segment, and maximum speed for each segment. However, the dynamic properties of traffic and transport are produced and collected every 2 minutes including average speed of vehicles, flow rate of traffic, CO2 emissions, and reservations and capacity of public transport. These traffic updates are further enriched with forecasts about the situation of traffic at a particular time in the future. These forecasts represent traffic flows, and are generated and maintained by the "traffic radar". Forecasts are periodically sent to the multi-agent traffic system and consist of cumulative flows on links and nodes. Density, speed and flow can be determined for each link/node based on these forecasts for a limited time-horizon (e.g. 2 hours).

The Traffic Radar follows the PROSA architecture [26] and uses the Delegate Multi agent system patterns to coordinate the different agents [27, 28]. Although the in-depth explanation of the "Traffic Radar" is outside the scope of this paper, some properties of the "Traffic Radar" are given below.

- Journeys can be virtually executed considering traffic flows, speeds and densities. The result of a virtual journey gives information on the predicted travel times and speeds on the visited nodes and links. Multiple journey generators finding a route from the origin to the destination can be distinguished:
  - Random search or heuristic search
  - Guided by latest known eco-route which is given by the multi agent traffic system
- Users collect alternative journeys and select a journey as intention. Automatic selection by means of a user avatar (representing the user`s preferences) is also possible.
- Known intentions (time and route) are accumulated on links and nodes in order to predict the link flows, speeds and densities. This information is matched to the historical and the current traffic state.

Effects of unpredicted traffic conditions (e.g. car accident or rain) are also incorporated whenever they occur. The traffic flows are adapted accordingly.

Transport segments within the transport network are modeled using infrastructure/transport agents, which exhibit all collected properties, calculate a cost based on these properties, and communicate with neighbouring agents regardless of their type, e.g. a road agent can communicate to a bicycle agent if they are physically adjacent. This approach creates a multi-layer of transport network, enriched with transport and traffic information. Every time a journey request is solved, the managing agent sends the route solution to the sensor agent, which forwards the solution to the commuter's mobile device. The environment hosts and controls the execution of all agents as depicted in Fig. 2.

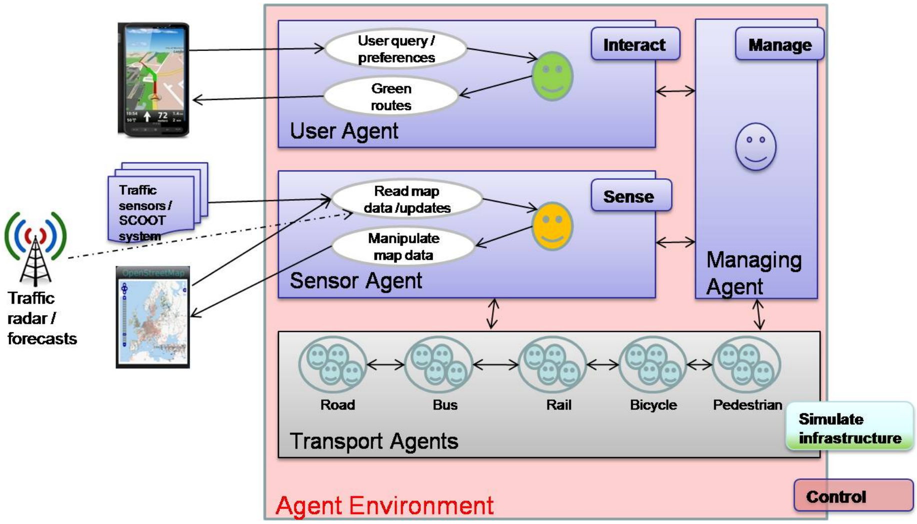

Fig. 2. A Multi-agent Architecture for Modeling Urban Transport Using Traffic Forecasts

3.3 Path Finding in the Multi-layer Transport Network

Path finding in weighted traffic networks is the process of searching for the shortest possible route between two points. The path is represented via a set of segments starting with the origin segment and finishing with the destination segment. Our multi-agent system creates a multi-layer transport network of different modes, where the weight of each transport segment is the cost of using this particular segment. Since our research focuses on reducing carbon dioxide emissions resulting from transport, we selected relevant emission-related variables to calculate the cost of road segments, as opposed to the use of the segment length only as in most typical cases. Therefore, the cost takes into account five main factors: *length of segment, current flow rate of transport, estimated* CO_2 *emissions, average speed of vehicles, and forecasted flow of transport in the future*. Length of segments is obtained from open street map data, whilst other real-time variables are obtained from other data collection systems, e.g. SCOOT [2]. Cost is determined according to function (1):

$$Cost\ of\ transport\ segment = \sum_{k=0}^{n} x_k\ a_k \quad (1)$$

where x is a configurable weight, and a is one of the above five factors, normalised. The weights add up to '1'. It is important to note here that current traffic flow is obtained from actual traffic sensors, while forecasted traffic flow is anticipated by the traffic radar. The above cost function is configurable and allows adding up other traffic variables as needed.

Once a weighted transport network is created for each mode of transport, the multi-agent system can process user journey requests and calculate potential intermodal routes according to the three algorithms below, which are selected rather for general testing purposes of the cost function (1). Yet a performance comparison between these algorithms and other approaches (e.g. ant colony optimisation) as well as a complexity analysis are left out of the scope of this paper.

- **Dijkstra algorithm**: this is a graph search algorithm for finding the shortest path between any two nodes in a positively weighted graph. For a particular source node, the algorithm finds the path with the lowest cost between that node and any other node. This algorithm has been widely used in route planning applications, with variations to improve its performance, e.g. [13].
- **A* algorithm**: this is an improved version of the Dijkstra algorithm, with a reduced search space. It uses a heuristic function to estimate the cost between any segment and the destination segment [14]. In our case, the heuristic function calculates the approximate physical distance between segments and the destination segment which is then used to determine which segment to visit next during the search.
- **Noticeboard algorithm**: this algorithm (details provided in [12]) aims to deliver multi-modal and innovative solutions, with each transportation segment monitoring the travel requests and "volunteering" to take a part in those travel requests which are relevant. A transportation segment can be a street but also could be a train journey or a bus journey. One segment would usually not be sufficient to satisfy the complete transportation request, in which case several segments will form a consortium. Each segment will "price" their participation in the consortium depending on their projected load at the time, where less busy and more eco-sound segments will be cheaper. This will allow a multi-criteria comparison of alternative routes, which will be represented as competing consortia of segments.

In our implementation, we endeavor to pre-process the weighted traffic network prior to finding routes to improve the performance of the aforementioned algorithms. The weights of the multi-layer network are recalculated only when traffic updates or forecasts are received by the sensor agent, otherwise the existing weights are used to recommend routes in which case no unnecessary agents' communication will occur. It is also worth mentioning that as soon as traffic changes occur, the multi-agent system recalculates the routes and dynamically updates the commuter with the new changes.

4 Implications for Traffic Management and Route Guidance

This research capitalises on the advancements, which software agents bring about to solve an increasingly important problem, that of the drastic increase of CO2 emissions as a result of traffic jams. Software agents are intelligent entities that can behave autonomously and react to unexpected, and fast-changing conditions of a specific environment [7]. These very factors quality agents to be an appropriate candidate for handling traffic conditions.

The subsequent table lists the factors that justify the rationale behind our architecture and how it addresses the problems of contemporary traffic in urban cities.

Table 1. Challenges of Urban Transport and Advantages of our Architecture

Main Challenges in the Contemporary Urban Transport	Features of Agents	Our Architecture
Continuous increase of car use and carbon dioxide emissions	**Situated:** direct connection with the environment through sensors and effectors	Models CO_2 emissions through multiple indicators and the cost represents the level of environment-friendliness of each segment
Need for manual interference to guide traffic. For example, human manipulation of phasing lights	**Autonomous**: ability to react independently	Commuters are re-routed automatically in real-time using their mobile devices to avoid major hold-ups and congestion
Traffic disturbances happen unexpectedly (e.g. traffic jam following an accident)	**Reactive**: ability to react to stimulus in the environment in a timely manner	Uses forecasts (e.g. accidents, rush hour … etc) about traffic flow to optimise solutions
Traffic affect each other (e.g. traffic jam on one road could affect traffic flow on another road in the same network region)	**Sociable**: agents talk to each other by exchanging messages	Transport agents communicate to each other regardless of their type (e.g. road, bus, rail) creating a rich and complementary multi-layer network
Lack of synchronisation between differing modes of transportation. A commuter who needs to combine the use of tram and bus, for example, might find it challenging to find a journey that suits his needs. This is due to the lack of integration between varying modes of transport	**Cooperative**: although autonomous in nature, agents can cooperate to achieve the same goal (e.g. the system's goal)	Calculates intermodal solutions that combine various modes of transports to fit commuter demands and constraints

To elaborate the advantages and application of our multi-agent system in route guidance, we discuss a worked example comparing route solutions without and with traffic forecasts. Let us consider a road region from a transport network which consists of 7 interconnected road segments, where 'O' signifies the origin and 'D' signifies the destination. The nodes in Fig. 3 represent road segments with their IDs. The numbers on top of each node signify the overall cost of using that node, e.g. the cost of using segment 3 is 15. The links in the graph represent the connections between transport segments, for example segment 4 is linked to segment 'O' and segment 5.

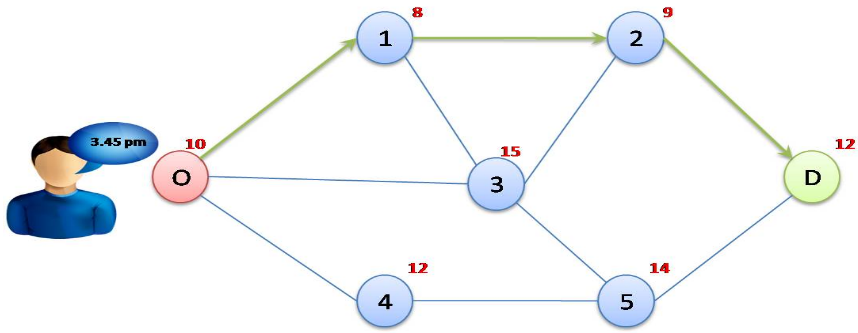

Fig. 3. Case 0, System Routing Recommendations without Traffic Forecasts

In the first case '0', the commuter wants to travel from 'O' to 'D' at 3.45 pm and submits his journey request using a mobile device. In this case, the user agent is notified with the new request which is then forwarded to the managing agent. The managing agent orders the sensor agent to fetch the latest updates about the current situation of traffic. As soon as available traffic updates are collected from traffic sensors, the road agents update their properties, recalculate their cost, and inform their neighbouring segments. Finally, the multi-agent system calculates a route solution for the commuter request and returns {O, 1, 2, D} to the mobile device via the user agent. The key point in this scenario is that the multi-agent system does not consider the situation of traffic in the future (e.g. at 4 pm) when estimating cost.

Unluckily, the commuter reaches segment 2 at exactly 4pm to find himself stuck in a huge congestion caused by traffic emerging from another road connected to segment 2, with a new cost 47 (Fig. 4). Such route guidance not only aggravates the traffic situation but also damages commuter's trust in the system.

In case '1', the multi-agent system receives, through the user agent, two new journey requests to travel from 'O' to 'D' at 3.45 pm and 4pm respectively. This time the road agents use the estimates of traffic flow at 3.45pm and 4pm received from the traffic radar to recalculate their anticipated overall cost. These costs are then updated as indicated by the arrows in Fig. 4. For instance, the cost of segment 1 is anticipated to increase from 8 to 12. For the first journey request, the multi-agent system dynamically diverts the commuter at segment 1 to evade the congestion predicted at segment

2 resulting in a new route solution {O, 1, 3, 5, D}. For the second journey request, the user agent returns {O, 4, 5, D} as the greenest solution to the mobile device. In both situations, our multi-agent system successfully exploits traffic forecasts to evade potential traffic jams and congestions and therefore reduce CO_2 emissions.

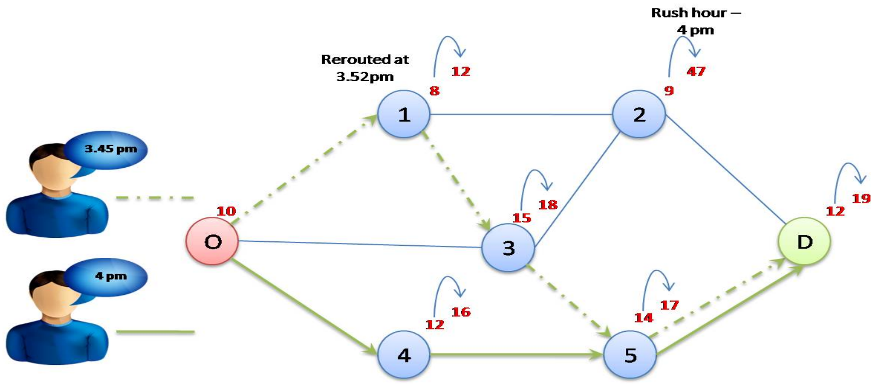

Fig. 4. Case 1, System Routing Recommendations with Traffic Forecasts

5 Conclusions and Future Plan

The paper discusses a multi-agent architecture that uses traffic forecasts to recommend route solutions to commuters. The architecture is innovative in the sense it covers various modes of transport including road, public transport, cycling routes, and pedestrian paths. It also uses various measures to calculate the cost of using each segment. The outputs are intermodal route solutions that accommodate commuters' preferences and demands such as time of travel and possible modes of travel. The multi-agent system is currently being tested using real-time Nottingham city transport data, with 755 actual road segments. It is part of our future research agenda to test and compare the performance of the above three algorithms in the case of serial journey requests and parallel journey requests. To make the comparison even more interesting, we are implementing a centralized and distributed version of each algorithm.

The dynamic updates of traffic to feed our multi agent system come primarily from sources of real time traffic data available in two participating traffic and management centres, Nottingham in the UK and Sofia in Bulgaria. Traffic data sensors in these two cities are indeed different, with Nottingham providing a rich landscape of traffic information about road density, traffic flow, and capacity of roads. Moreover, these two participating sites form two interesting cases to deploy and test our system. It is our goal to evidence that the multi-agent system is applicable to different contexts with substantially diverse capabilities, and able to solve traffic problems relevant to each case. However, we anticipate the multi-agent system to perform better in the Nottingham test site.

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