Master Thesis

Using Multi-Agent Simulation to Design a Solar Energy Distribution System

Supervisor Professor Toru Ishida

Department of Social Informatics
Graduate School of Informatics
Kyoto University

George ZHOU

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Abstract

The social system of modern urban is always large-scaled and complicated, which makes it difficult to predict dynamic changes. To provide people comfortable living environments, socially-efficient urban system design is beyond the capability of human computation. To investigate this problem, this paper try to consider the Multi-Agent Simulation (MASim).

When designing social systems, the expected to-be images of such systems are always pre-defined. Therefore, this paper take a unique approach to evaluating the as-is design that can realize the to-be system on the MASim, where MASim is used as an evaluation unit. However, a large amount of computation is required to find the good design for trying the various combinations of system conditions. This paper propose a new supporting approach for system design which combines the good design search by search algorithms and the evaluation on the MASim environment.

This research uses the MASim evaluation approach to design a solar energy distribution system based on the electric vehicle (EV). Moreover, this paper analyze the complication of the actions of the new system with people, EVs, new energy resources, and show the possibility to compute good design of the new system. Further, this paper discuss the effectiveness of applying MASim as tools of social system design. MASim is suitable for the new system. Because, MASim is useful when if you want to capture individual human behavioral changes, and by integrating human behavioral changes, and it is all different that each energy consumption situation, individual situation like ownership of PV and EV individual behavior patterns. Thus, extremely complex situation was created. In that case, MASim is model individual actors as an agent cause the representation of the situation and observation can be easily achieved.

In our proposed approach, first, we paper model the object systems and define the evaluation functions, variables that describe the attributes of social systems, functions for computing favorability of designed social systems. Then,

in order to find the good solution with multiple conditions, this paper repeat the process for evaluating the candidate solutions generated by the search algorithms using the MASim. Further, this paper conduct a series of experiments on the MASim environments and get three observations as follows. The result shows the possibility of performance prediction under any conditions by combining search algorithms and MASim to design unknown social systems as follows:

- Under multiple conditions (system participation rate, drop acceptance range, electronic power exchange station number, distribution pattern) , the combination of the good design is 60 %, 2000m, 60, 1:1:3, while the combination of worst design is 20 %, 500m, 40, 3:1:1. That is to say, it is possible to get a good result with small number of electronic power exchange stations if most participants accept long-distance drop and electronic power exchange stations are built in the center of the urban.
- In order to confirm the status of solving the depression of PV power generation and reverse power flow , this paper compare the amount of PV power generation and reverse power flow. The result shows that the generated power is used more effectively in the good design case than the worst design case described above. Moreover, the total amount of reverse power flow has a 40% improvement in the good design case.
- This paper compares the amount of received power from EV in the electronic power exchange stations to confirm the effectiveness of the PV power collection/distribution system by EVs. The result also shows that the total amounts of reverse power flow are significantly different in the good design case and the worst design case, which is 501kWh and 118 kWh respectively.

In this research, this paper propose the system that combines transportation and electronic power, and conduct the simulation. However, our focus is to reveal that MASim can contribute to the globally important problem of social system design rather than implement such systems in the real world. The research on energy problem is becoming more and more important in recently years. Our research can also be regarded as an important step in this area and be expected to be applied in existing researches.

マルチエージェントシミュレーションに基づく太陽光エネルギー流通システムのデザイン

周 劼

内容梗概

現代都市の社会システムが複合した大規模複雑系であり，動態の予測は非常に困難である．住み暮らす人々に安心と快適を提供し，社会に高効率もたらす都市規模のシステムデザインは人の計算能力を超えている．この課題に対してマルチエージェントシミュレーション（MASim: Multi-Agent Simulation）による接近が可能である．

一方，社会システムデザイン時，社会システムの将来像の大枠が決定されているケースが多い．したがって，本研究は，システム将来像を実現するための現段階デザインを MASim 上で評価を行い，MASim を評価装置とした逆アプローチ考えた．しかし，数多くのシステム条件が存在する上，システム条件の組み合わせると膨大な計算量となり，ベストデザイン発見には膨大な計算が必要とされる．そこで，探索アルゴリズムによるベストデザインの探索と MASim で構築した環境での評価，両者の組み合わせて新しいシステムデザインの支援手法の試みる．

本研究では，新たに形成しうる電気自動車による太陽光エネルギー流通システムを注目してマルチエージェントシミュレーションを評価装置として利用して，人，電気自動車，新エネルギーリソースから構成された新システムの挙動の複雑さに対処し，新システムのベストデザインが計算可能であることを示し，社会システムデザインのツールとして MASim の利用を主張する．

提案手法では，まず，対象とするシステムのモデル化と評価関数を定義し，社会システムの特性を表わすための属性変数と取りえる変数値，およびシミュレーションの結果に基づいて，デザインする社会システムの好ましさを表す定量値を計算する関数を決定する．次に，複数条件の最良解を見つけるために，探索アルゴリズムで解の候補を生成し，MASim で構築した環境で評価するという良好デザインの発見プロセスを繰り返し，最も評価値の高い解を探索する．

MASim を用いた理由として，エネルギーが直接に人々の生活に影響する．人の行動変化を個々に捉えてその集積によって全体の変化を把握したいとき，MASim を用いることが有効である．また，動的なシステムの構成要素によって生まれ

る複雑な状況に MASim が行動主体をエージェントとして個々にモデル化し状況の表現，観察が容易に実現することができる．

MASim で構築した環境で実験を行い，実験結果について，３つの観点で以下のように示す．また，マルチエージェントと探索アルゴリズムの組み合わせによって，未知の社会システムデザインに関して，任意の指標の下に性能予測とともに，示唆的な知見を得ることが可能であることが分かる．

- 最良デザインの発見について，システム参加率，立ち寄り許容範囲，車載電力交換サイトの設置数，配置パターン，複数の条件の最良の組み合わせを得た際，最良デザイン（良好ケース）が {60 %，2000m，60 基，1:1:3} であり，不良デザイン（不良ケース）が {20 %，500m，40 基，3:1:1} であった．つまり，長距離の立ち寄りを許容すること多くの参加者を集め，人がより多く集まる都心部を中心に電力交換サイトを設置することで，交換サイトの設置数をやや抑えならが，よい結果が得られる可能性を前者の結果は示唆している．
- PV 電力発電量と逆潮流量について，PV 電力活用，逆潮流量の抑止という問題点の解決状況を確認するために，施設での PV 電力発電量と逆潮流量を比較した．上記の良好なケースでは，不良ケースと比べて，発電量が有効利用されていたことが確認できた．逆潮流の総量に関して，良好ケースが 40 %ほど改善された．
- 車載電力交換サイトで EV からの受電量について，想定した EV による PV 電力の集約・分配システムどれくらい機能しているかを確認するために，車載電力交換サイトで EV からの受電量についても比較を行った．逆潮流総量では，それぞれのケースが 501kWh，118 kWh であるため，二つのケースの間の逆潮流総量の差があることが分かった．

本研究では，交通と電力のシステムを融合するシステムを構想し，シミュレーションを行った．しかし，筆者の狙いは，このシステムの実用性を問うことでなく，日本はもちろん，世界的に重要な課題を取り扱った社会システムデザインにマルチエージェントシミュレーションが貢献できることを明らかにしたい．しかし，エネルギーに関して，近年，研究活動が活発化しつつあり，本研究で提案したアプローチを既存の研究に応用することも，今後重要な課題の一つである．

Using Multi-Agent Simulation to Design a Solar Energy Distribution System

Contents

Chapter 1 Introduction

The social system of modern urban is always large-scaled and complicated, which makes it difficult to predict dynamic changes. To provide people comfortable living environments, socially-efficient urban system design is beyond the capability of human computation. To investigate this problem, this paper try to consider the Multi-Agent Simulation (MASim)[1].

In transportation system research field, there are some previously work have been attempts to understand by simulating the traffic flow based on the driver model[2, 3, 4], in power resource research field, there are previously works have been analyzed some electrical energy management effect[5].On the other hand, a proposal of pedestrian flow simulation for supporting evacuation plan in urban city[6], and using simulation technique attempt to design a whole smart city[7]. So, considering MASim is very good way to help us discovering potential problems or pre-verification policies, MASim can be very helpful when we design new social systems.

Issue: What's the social system in this paper need to be considered? This paper believes that every social activity is based on energy. In recent years, new energy resources and the way bring new energy resources in social system have been searching around the world. Our social activities are practiced by the traffic, which generated from human, things, information come and go, based on consuming energy. Considering this reason, from now on it is absolutely essential that this paper should discuss about energy system and transportation system [8]. Under the social conditions of the environment orientation, Electric Vehicle (EV) and Photovoltaic (PV) power generation system could spread rapidly. It will bring a new situation that EV 's and PV 's users become to produce and transport energy. If transportation and distribution of electric energy connected closely by human behavior as a medium, the line bounded two different system will disappear. Therefore, this paper considers a solar energy distribution system integrated EV by using Multi-Agent Simulation and shows the good design of the new social system integrated with existing different systems can be calculated. So the issue will be how to deal with the complexity of system behavior, such as the individual agents, change their travel behavior based on daily status in transportation, or, change their contribution to power distribution according to the changes in travel behavior.

Goal: To face the issue, this paper suggests that iterate creation and evaluation of the simulated phenomenon on the simulator through a combination of search algorithms and multi-agent simulation to find the good solution. That means, good system design which minimize the distance between the values of social indicator this paper aimed, decide by evaluation from the simulation results. Basically, this paper proposes a method based on MASim, achieve the calculation of social design as a indicator that is the behavior of the crowd. Further, this paper discuss the effectiveness of applying MASim as a tool in social system design.

Chapter 2 Related Work

In the section, first, this paper forced on the energy issues around the world. Secondly, this paper shows the basic information about EV and PV which are the important way can address the energy issues. Moreover, this paper introduce two related works and explore the possibility of social system newly constructed, based on a concept known as Vehicle-to-Grid power or V2G power.

2.1 Global Energy Issues

Recently years, considering dealing with the global environment problem or compact city, governments around the world has begun to show movements to a low carbon society. Based on [9], if this paper look at Table 1, we will see that world energy consumption is growing because of the growing world population and using electronics, and it is become difficult to respond the increasing power demand. Besides, it has been an increasingly serious concern the problem of global warming caused the use of coal-fired for power generation. such as U.S. coal crude oil issue, U.S. is a country highly dependent on traditional energy resources.Table 1 constitutes that In 2010, U.S. crude production reached its highest level since 2003[1)].

However, both crude oil and coal are finite, so it cannot be avoided that these resources will run out one day. Thus, it is necessary that we need consider use the energy more efficient and find new more safer and secure energy resources. Therefore, President Obama of the United States set a short-term goal and long-term goal. Short-term goal shows that they will double the renewable energy generating capacity to 10% by 2012. This short-term goal which is expected to already realized, is equivalent to the amount of increase in the supply of electricity consumption of 60,000 American families. Long-term goal shows that they aim to account for 25 percent of the country's electricity consumption renewable energy at the end of 2025 [10].

In Europe, the EU's leaders endorsed an integrated approach to climate and

1) Based on EIA's online data, Available from: `http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRFPUS2&f=A`.

Table 1: World energy consumption by country grouping (quadrillion Btu)
Source : U.S. EIA

Region	2008	2015	2020	2025	2030	2035
OECD	**244.3**	**250.4**	**260.6**	**269.8**	**278.7**	**288.2**
Americas	122.9	126.1	131.0	135.9	141.6	147.7
Europe	82.2	83.6	86.9	89.7	91.8	93.8
Asia	39.2	40.7	42.7	44.2	45.4	46.7
Non-OECD	**260.5**	**323.1**	**358.9**	**401.7**	**442.8**	**481.6**
Europe and Eurasia	50.5	51.4	52.3	54.0	56.0	58.4
Asia	137.9	188.1	215.0	246.4	274.3	298.8
Middle and East	25.6	31.0	33.9	37.3	41.3	45.3
Africa	18.8	21.5	23.6	25.9	28.5	31.4
Central and South America	27.7	31.0	34.2	38.0	42.6	47.8
World	**504.7**	**573.5**	**619.5**	**671.5**	**721.5**	**769.8**

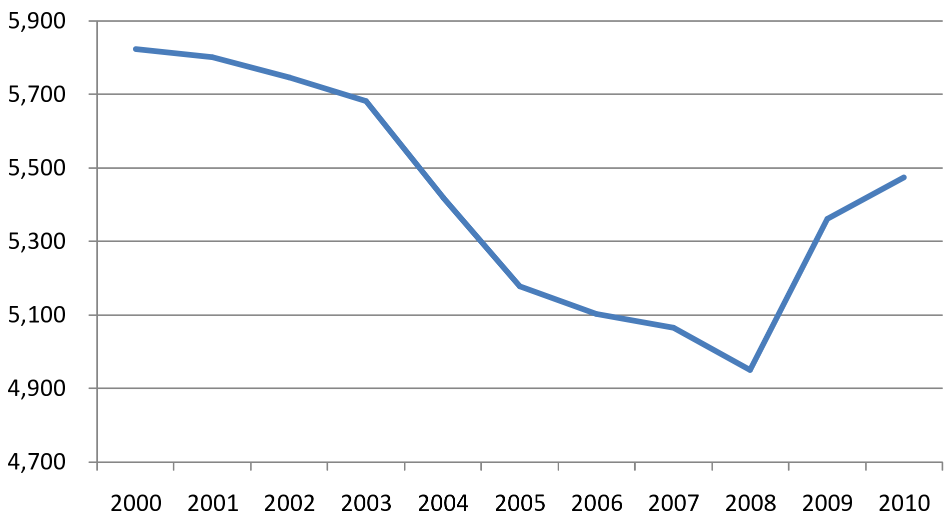


Figure 1: U.S. Field Production of Crude Oil (Thousand Barrels per Day)
Source : U.S. EIA

energy policy that aims to combat climate change and increase the EU 's energy security while strengthening its competitiveness. They committed Europe to transforming itself into a highly energy-efficient, low carbon economy. Because of that a new environmental policy called " 20-20-20 " , which will be achieved by 2020 based on three keywords " 20, " was already set up in 2007 as a goal to reduce greenhouse gas emissions in the region policy [11]. The three keyword " 20 " each means: a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels; 20% of EU energy consumption to come from renewable resources; a 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency.

A lot of EU member countries has been introduced such as the feed-in tariff(FIT) price system, which is a policy mechanism designed to accelerate investment in renewable energy technologies. It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology. Technologies such as wind power, for instance, are awarded a lower per-kWh price, while technologies such as solar PV and tidal power are offered a higher price, reflecting higher costs. The tariffs give three financial benefits:

- A payment for all the electricity you produce, even if you use it yourself.
- Additional bonus payments for electricity you export into the grid.
- A reduction on your standard electricity bill, from using energy you produce yourself.

In order to solve global energy problems, it is another way that makes an effort to improve transportation. Transportation of the United States accounts for more than 70 percent of U.S. oil consumption. Obliviously, in order to leave the current situation of oil dependence, changing the current state of the traffic is the most effective way.

Based on " Energy, transport and environment indicators[12], " transport cost the most final energy consumption, Table 2 shows final energy consumption in the EU-27 recorded slight annual deviations between 1999 and 2009. At sector level, the largest growths were observed in services (14%) and transport (8%), whereas energy consumption by households showed a moderate increase (2%)

Table 2: Final Energy Consumption, by sector, EU-27 (Mtoe)
Source : Eurosta

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Transport	**341**	**345**	**348**	**353**	**364**	**367**	**375**	**380**	**378**	**368**
Industry	329	329	325	339	337	333	326	325	316	269
Households	293	302	293	298	301	302	300	284	297	295
Services	115	127	125	131	134	136	139	136	142	141
Other	42	42	41	51	51	54	54	42	43	41

and energy consumption by the industrial sector declined by 15%. In 2009, the transport sector consumed almost a third (33%) of EU-27 final energy. the most sector in total final energy consumption. Moreover, within the transport sector of the EU-27, road transport was the most energy consuming mode with an 82% share of the total in 2009. The situation was similar in Member States. Road transport accounted for the largest share of their energy consumption and even exceeded 90% of the total among new Member States. Considering the fuel dependent on oil for 98%, this way is not sustainable anymore.

2.2 Impact of EV and PV

The growing availability of EV is in progress. In U.S., President Obama announced that with more research and incentives, U.S. can break our dependence on oil with befouls, and become the first country to have a million electric vehicles on the road by 2015. In EU, each EU member countries have been made their own policy activities[1)]. For example, in Germany, the government plan to achieve 1 million EV by 2020[2)]. If it is achieved, it means EV account for 4% of all cars in Germany. For the long-term goal, the government plan to achieve 6 million EV by 2030. In France, Ministry of Environment plan to achieve 2 million green cars by 2020.

[1)] JETRO: EU member's activities, Available from: `http://www.jetro.go.jp/world/europe/reports/07000740` (2010).

[2)] DOE: Plan to put one million advanced technology vehicles on the Road, Available from: `http://energy.gov/.` (2011)

Battery is the key problem for EV. In U.S., the Recovery Act included $2.4 billion for battery and electric drive component manufacturing and for electric drive demonstration and infrastructure, and investments that are already transforming the advanced vehicle batteries industry in the United States. Based on 2 in 2009, the U.S. had only two factories manufacturing advanced vehicle batteries that power advanced technology vehicles and produced less than two percent of the world 's advanced batteries. However over the next few years, the United States will be able to produce enough batteries and components to support 500,000 plug-in and hybrid vehicles and will have the capacity to produce 40 percent of the world 's advanced batteries (2015). In part because of these strategic Recovery Act investments, battery costs are expected to drop by half (2009-2013), and by 2030 battery costs are expected to drop in 1/10[13].

In EU, we see from Table 3 that by 2020 the energy density of battery cells can be expected to increase by a factor of two (for current Li ion battery technology) to three or above (for next generation batteries). It is foreseen that by then the lifetime of the battery will increase by a factor of up to three such that it matches the lifetime of the car, and the cost will be dropping to at least 1/3 of today 's values, and to even far less if mass volume production is achieved where the minimum cost eventually will be given by the cost of the raw materials [14].

At section 2.1, in order to address the global energy issues this paper shows the potential of renewable energy. Further, in this section, this paper would like describe the PV, which is one kind of renewable energy. In EU, considering renewable energy, European Renewable Energy Council (EREC) published " RE-thinking 2050: A 100% Renewable Energy Vision for the European Union " in 2010[14]. In Table 4([15]), the Renewable Energy Directive sets an overall target of a share of at least 20% renewable energy by 2020. As far as electricity is concerned, the European Commission expects that the share of renewable energy will need to increase to 34%. By 2020, all RES-E technologies will contribute to about 39% of the total electricity consumption. The RES contribution to power demand increases further in 2030, where the share of renewable electricity will account for 65-67%. By 2050 renewable electricity will provide

Figure 2: EV Battery Cost Reduction Forecastin U.S.

Source: U.S. DOE Vehicle Technologies Program, Energy Storage R&D, 2010 Annual Progress Report

Table 3: EV Battery Road Map EU

Source: European Green Cars Initiative

Batteries for EVs	**Energy Density (cells)**	**Life Time (calender life)**
today	140 Wh/kg (200 for laptop batteries)	7 yrs. (lack of reliable data for EV)
2012	220 Wh/kg (140-300)	9 yrs. (8-10 yrs.)
2016	300 Wh/kg (150-500)	11 yrs. (10-12 yrs.)
2020	450 Wh/kg (250-700) $>$ 1000(LiO_2)	17 yrs. (10-20 yrs.)

Table 4: Contribution of Renewable Electricity Technologies to Electricity Consumption (TWh)
Source: EREC

	2007	2020	2030	2050
Wind	104 (19%)	477(35%)	833(35%)	1552(31%)
Hydro	325(60%)	384(28%)	398(17%)	448(9%)
PV	**5.4(1%)**	**180(13%)**	**556(23%)**	**1347(27%)**
Biomass	102(19%)	250(18%)	292(12%)	496(10%)
Geothermal	5.8(1%)	31(2%)	169(7%)	601(12%)
CSP	0.8(-%)	43(3%)	141(6%)	385(8%)
Ocean	-	5(-%)	18(1%)	158(3%)
Total RES-E (TWh)	543	1,370	2,407	4,987
Total share of RES-E(%)	16%	39.20%	65%	100%
Total Non RES (TWh)	2851	2125	1296	0
Total Electricity Consumption	3394	3495	3703	4987

for 100% of the EU 's power demand. As can be seen, a significant increase of electricity demand is expected between 2030 and 2050. This is mainly due to two factors: an increase in heat pumps usage and a modal shift of both passenger and freight transport to less energy intensive public transport such as bus and rail as well as a shift of fuel usage towards the electrification of road transport.

The cost of power generation is the key problem for PV. Governments around the world show the movements of strategic scenario for reducing the power generation cost of PV. E.g. in U.S., by 2030 solar panel components for 80 percent less than the current cost in 2009. However, due to improved penetration of PV, the problem of surplus power would arise. If interconnection of PV is too centered, it causes reverse flow to the distribution system (reverse power). Then because the reverse power exacerbates power quality [16], such as output suppression, the measures must be taken.

2.3 V2G Concept

As we already discussed, since the number of PV increased, there are a lot of challenges, such as when the reverse power flow happened, the damage caused by the rise in the voltage distribution system, frequency fluctuation caused by reverse power fluctuation, and low operating rate caused by the surplus power. Also since the number of PV increased, there are a lot of challenges, such as energy demand, charging infrastructure, manage charging, which are all important factor for the spread. So, no matter EV or PV, it is necessary to find solution for these issues.

Considering increase in the number of EV in the future, there is a study suggest that it can help stable supply of electricity, and deploy low cost renewable power that connect EV to the power grid（V2G: Vehicle-to-grid）[17]. The study attempts make a point that peak cut, stabilize the unstable renewable power can be resolved by using EV ’s battery as a buffer.

Figure 3 schematically illustrates the concept of V2G. The basic concept of vehicle-to-grid power is that EV provides power to the grid while parked. The EV can be a battery-electric vehicle, fuel cell vehicle, or a plug-in hybrid. EV can charge during low demand times and discharge when power is needed, connections between vehicles and the electric power grid. Electricity flows one-way from generators through the grid to electricity users. Electricity flows back to the grid from EV the flow is two ways.

According to [17], in U.S., since average vehicles in the United States travel on the road only 4-5% of the day, and at least 90% of personal vehicles sit unused (in parking lots or garages) even during peak traffic hours, the size of a possible V2G resource can be quite large: placing just a 15 kW battery in each of the existing 191 million automobiles in the United States would create 2865 GW of equivalent electricity capacity if all the vehicles supplied power simultaneously to the grid-an unlikely occurrence. This amount is more than twice the total nameplate capacity of all American electric generators in 2006. This paper would like to point out that this is just a quick calculation that describes the V2G power potential is very large, and does not consider the energy storage and the amount of time power could be drawn relative to both

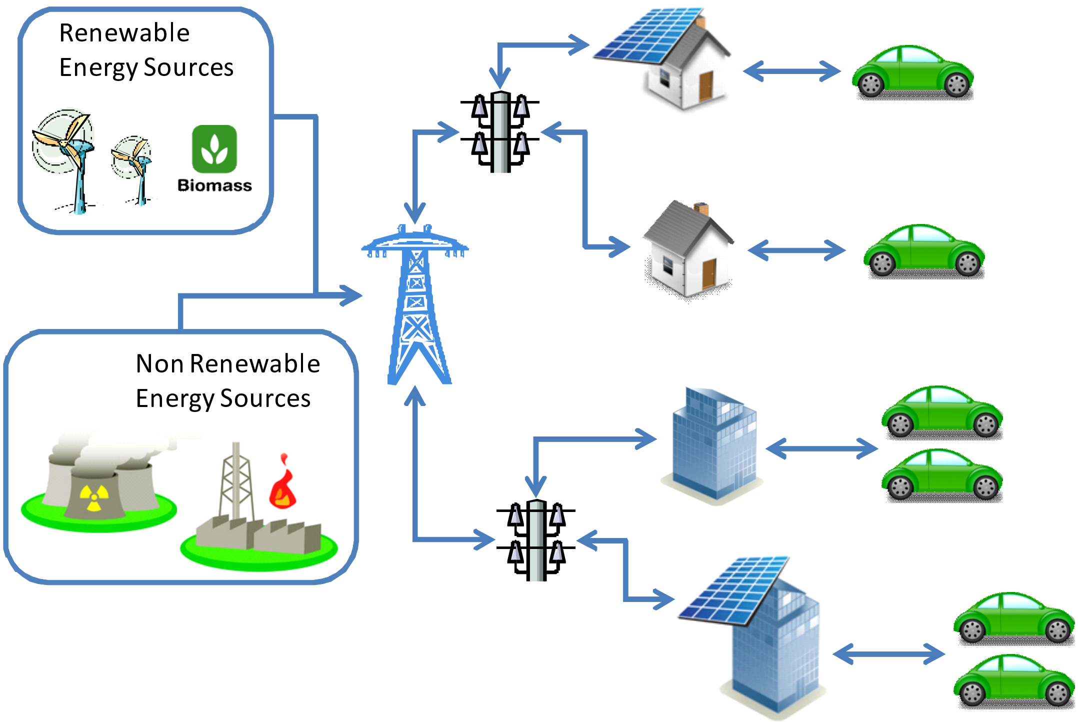


Figure 3: V2G Concept

wind lulls and driving needs.

Based on more precisely the amount of wind power that would be enabled by a large V2G fleet have been calculated[18]. These calculations suggest that V2G would serve the majority of need for integrating wind into the electrical system, which means V2G enables multiple types of electric drive vehicles to play valuable roles as back-up and/or storage for wind power, eventually making very large scale wind integration more stable and more economical.

So this paper is also based on V2G concept as well. Our simulation performs the leading and distribution of renewable power based on V2G. Distribution channel, distribution opportunity on power distribution through the vehicle battery of EV, is defined by human behavior and decision made, who actually is carrying energy. Especially, In Japan, power system stability is quiet high. It is not necessary that distribute electric power by EV, as a backup storage system. Considering renewal energy PV, it is possible to create new values that distribute electric power made from PV by EV. EV and PV spread among people in urban city - a lot of people and system function get together, it could create large-scale citizen to get in energy production and transportation. Thus, in this paper we validate user participation city power distribution system flexibility to distribute and aggregate surplus PV power occur in distributed location, by using EV based on MASim.

2.4 Energy and Multi-Agent Simulation

In recent years, about energy issues, Japan is, of course, worldwide have been attracted a lot of attention. However, there are still a lot of Technical challenges have to be done in order to achieve the V2G concept. There are some privies work to study how to manage the new resource, such as frequency control, reduce peak load of power.[5, 19, 20, 21, 22]. And there are also some privies work to study how to design the mechanism for the new system, such as electrical market that integrated EV[23, 24, 25, 26]. Moreover, such as construction of infrastructure charging, installation methods performance, the design of the entire urban social system challenges should be solved. There are also some related works based on MASim. In this section, we would like to introduce two works, which focused on energy and applied MASim in their method.

Online mechanism design for electric vehicle charging

In [23], a new pricing mechanism that could change the way in which electric vehicles are charged. It is based on an online auction protocol that makes it possible to charge electric vehicles without overloading the local electricity network.

As a background plug in hybrid electric vehicles are expected to place a considerable strain on local electricity distribution networks, requiring charging to be coordinated in order to accommodate capacity constraints. To address these concerns, electricity distribution companies that are already seeing significant EV use have introduced time of use pricing plans for electric vehicle charging that attempt to dissuade owners from charging their vehicles at peak times, when the local electricity distribution network is already close to capacity. There are approaches separate the scheduling of the charging from the price paid for the electricity, but, they are unable to preclude the incentive to misreport.

To address this issue, researchers turned to the field of online mechanism design. They designed a mechanism that allows vehicle owners to specify their requirements (for example, when they need the vehicle and how far they expect to drive). The system then automatically schedules charging of the vehicles' batteries. The mechanism ensures that there is no incentive to 'game the system' by reporting that the vehicle is need earlier than is actually the case, and those users who place a higher demand on the system are automatically charged more than those who can wait. The mechanism leaves some available units of electricity un-allocated. This is counter-intuitive since it seems to be inefficient but it turns out to be essential to ensure that the vehicle owners don't have to delay plugging-in or misreport their requirements, in an attempt to get a better deal.

In the experimental evaluation, They empirically simulate the mechanism in a real-world setting, and showed that the proposed mechanism is highly robust, the mechanism was shown to increase the number of electric vehicles that can be charged overnight, within a neighborhood of 200 homes, by as much as 40 per cent, which achieves better allocative efficiency than any fixed-price benchmark, while only being slightly suboptimal w.r.t. an established cooperative scheduling heuristic.

They share certain same angle in that point of our's observation, that in order address the issue applied the MASim in the proposed method, by considering system features about complex social system-power grid integrated EV. However, in this paper a reverse simulation approach is proposed, which a virtual environment represented by MASim, and create results that match the real social indicators. Further, with evolved virtual environment agent, if the results match the real social indicators will be attempted. Moreover, in the paper purpose was to obtain a valid design of unknown social system. It is a technique will evolve the environment surrounding the agent, the nature of which has fixed as each one has individual behavior model.

Deploying Power Grid-Integrated Electric Vehicles as a Multi-Agent System

In [22], an implemented and deployed system, based on Multi-Agent System for integrating a group of EDVs into the electricity grid. It is described the various types of power markets and presented an implementation of a multi agent system that allows EDVs to participate in the regulation market.

Grid-Integrated Vehicles (GIVs) are plug-in Electric Drive Vehicles (EDVs) with power-management and other controls that allow them to respond to external commands sent by power-grid operators, or their affiliates, when parked and plugged-in to the grid. In more advanced cases, these GIVs might sell both power and storage capacity back to the grid in any of the several electric power markets, based on V2G power.

Although individual EDVs control too little power to sell in the market at an individual level, a large group of EDVs may form an aggregate or coalition that controls enough power to meaningfully sell, at a profit, in these markets. The profits made by such a coalition can then be used by the coalition members to offset the costs of the electric vehicles and batteries themselves. In this paper we describe an implemented and deployed multi-agent system that is used to integrate EDVs into the electricity grid managed by transmission service operator named PJM. And researchers decided to focus on the regulation market, which is one kind of the power markets run by the transmission system operator.

There are two mainly kind of agents have been implemented. VSL(Vehicle Smart Link) agent and aggregator agent. The VSL agents look after the best interests of the owner or driver of the car, inside the cars. The operation of this VSL agent is based on the simplified finite state machine. The aggregator (a coalition server) is responsible for aggregating a group of EDVs, for abstracting away the details about the individual vehicles and for presenting them as a single resource to the transmission system operator. The aggregator agent is not only responsible for grouping the vehicles come together to form a coalition, but also decide, the capacity can a coalition of EDVs report to the grid operators, the vehicles within the coalition should be used to service the power requests, the profit be fairly distributed amongst the coalition participants. However, the problem of integrating EDVs into the electricity grid is a novel problem that opens up new avenues of research within the multi-agent community.

The research group use 5EDVs to evaluate the system by describing its operation over the first nine months of 2010. System performance was confirmed by Regulation Capacity Offered, Total number of hours plugged in, amount of money earned by the EDVs (in US$). As a result, the amount of regulation capacity offered and the amount of money earned is directly proportional to the number of hours plugged in. Based on the data, if an EDV is plugged-in and providing regulation services for 15 hours a day, EDVs owners can expect to make between 1,200 and 2,400 dollars a year in the regulation market. This is a significant amount of money that can be used to offset the high costs of EDVs.

The research group set the agent in each car which is real, has an individual behavior model, and based on users point of view, measured time of connection to the grid and profit from the contribution when they decide to connect to the grid. As a result, by jugging the contribution to regulation capacity, very meaningful results were obtained to effect power management. However, only 5 cars have been deployed on the system, so, scalability of car's number should be discussed. Researchers share certain similarities point in that environment got agent in, was evaluated, with the nature of which has fixed as each one has individual behavior model. In this paper, the purpose was to obtain a valid design of unknown social system, so the social system environment was built on the simulation. Further, launched agents based on it, repeatedly to evaluate the candidates based design of complex social system of social indicators was decided in advance to emergent discover good system design.

Chapter 3 Solar Energy Distribution System

In this section, this paper show an overview of the solar energy distribution integrated EV system based on V2G concept, after that this paper discuss why MASim is necessary, by showing that MASim are suitable for the new system.

3.1 Solar Energy Distribution System Overview

This paper is to find the good design of PV power distribution system to achieve that is integrated in the urban transportation system. Therefore, how was it validated that the surplus PV power occur in distributed location effect the amount of power lead from the power system, and PV power consumption, by the process of aggregation and distribution of power progress at the same time as the power consumption of each individual human, based on MASim.

Figure 4 shows an overview of the solar energy distribution integrated EV system. This simulation is executed as a step one day, and power use in the homes or other facilities (artifacts), power factor and the running of the EV, also the system power and PV power will be considered as a power supply source.

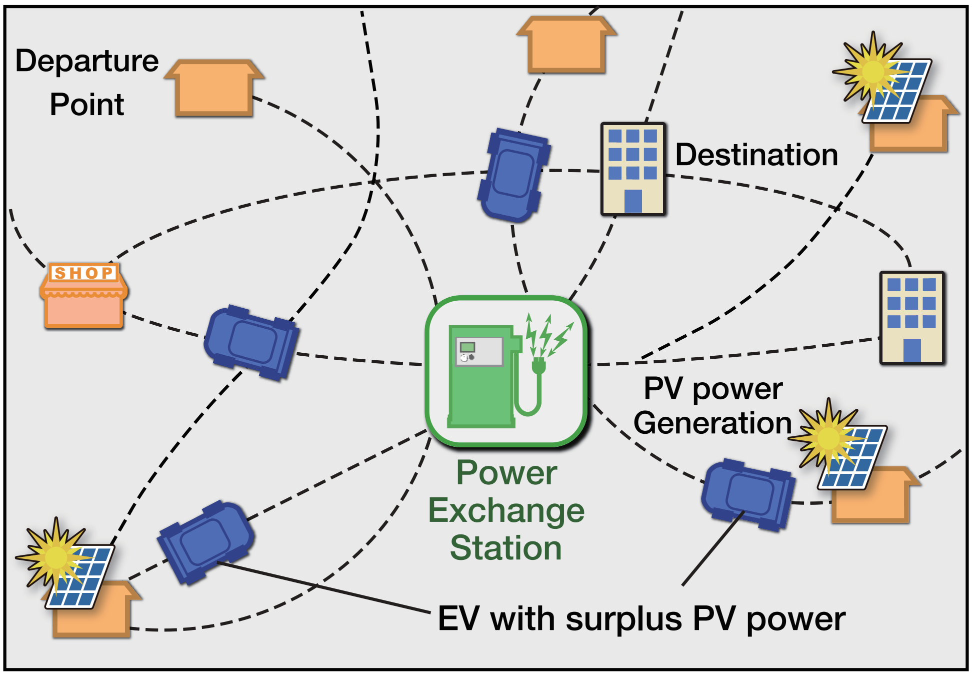


Figure 4: Solar Energy Distribution System Overview

Each individual EV determines the action plan every day, and run according to the plan, based on the table Origin - Destination (table OD[1)]) included location elements such as homes, offices and supermarkets, each own power demand, and surplus power. Extra PV power will distribute by EV.

To be more specific, a new provided aggregator called car surplus electric power exchange station will be set nearby homes or other facilities(artifacts), then EVs, which have surplus power and other EVs, which need power can stop by aggregator, the behavior of charge and discharge through the batteries at power exchange station, the power transfer between consumers and suppliers could be achieved [2)]. Normally, if the surplus PV electric power generation is expected, each supply system at home, reduce the amount of power autonomously. Otherwise, reverse power flow, which cause electric power quality degradation is going to occur.

The system proposed includes EV and PV, take advantage of the efficiency to use a new energy-PV can be expected. It is because following discussion: First, considering production of PV power, PV power is usually produced at home, company, which is different from traditional energy resources that can be centrally managed, such as thermal power, nuclear power. Therefore, the production of PV power depends on distributed location. Besides, production of PV power is also determined on the amount of sunshine. Therefore, the production of PV power depends on time line, because produced only during the day when there is sunshine, cannot be produced at night; Secondly, considering consumption of PV power, it is based on each people who has their own standards of behavior, and lifestyle. Some people consume more power, some people consume less power, and it all based on their own needs.

Moreover, take a hypothetical example, if power source for human consumption that consists only of power and PV power system, there are people don't have a PV power generating device only consume system power. And there are people have a PV power generating device only consume PV power instead of

[1)] OD is abbreviation of Origin - Destination

[2)] Note that, if there is not enough power in battery at power exchange station, the system power will be charged. This behavior is the same as the normal charging station.

system power. There are also people have a PV power generating device only consume PV power but still need system power because they need. There are also a variety of consumption patterns can be considered. So, in order to use the power efficiency PV, it is necessary to balance the production and consumption progressing at the same time, because both patterns of production and patterns of consumption is complex. In this paper, through the aggregation and distribution of PV power to produce distributed, we suggest share the energy on the system - " Energy Sharing " concept. " Energy Sharing " concept means PV power can be shared by transportation between production side and consumption side or between required side and surplus side, and system environment becomes available, which PV power available to the efficiently and reducing the power consumption of the power system.

In proposed system, how was it validated that the surplus PV power occur in distributed location effect the amount of power lead from the power system, and PV power consumption, by the process of aggregation and distribution of power progress at the same time as the power consumption of each individual human, based on MASim. Let's suppose that there are two people A and B. A is businessman who drives EV to go to work every day, and he doesn't have PV power generation device, so, when he needs charge system power is used. B is housewife who doesn't drive EV much, only when she needs shopping, and she has PV power generation device, so when she need charge, PV power is used. Unfortunately, because she doesn't drive EV much, consumption of PV power is small, as a result, surplus PV power was created. Traditionally, A uses system power every time when needed, meanwhile, B creates surplus PV power, if she keeps generating PV power. However, when B is driving EV, she can give the surplus PV power to power exchange station, if she want, this time B can stop by power exchange station, use surplus PV power to charge the car, instead of going back to home to charge the car with system power, based on " Energy Sharing " concept.

As a result, system power consumption is suppressed, and full advantage of the PV power will be taken, and, it will bring a good result for the entire system. The conclusion is easy and simple to say only because we only considered two people and the relationship between this two people. In the real social system such as power system, transportation system, there are thousands of people included, and the numbers of relationship between people are countless. Each people act by their own decision-making, and that create a complex situation, as a results, it is not certain that how the entire system behavior change looking from the big picture. Moreover, when designer design a complex massive system as we already discussed, it will be hard to make a decision.

Based on above discussion, this paper try to find the system requirements to achieve the following two points, eliminate the uneven distribution of renewable power, by allowing the distribution of power by EV.

- Reducing the lead amount of system power draw.
- Suppressing the amount of PV power cause reverse power flow.

To achieve this, it is necessary to adjust for a wide variety of conditions to configure the system such as power consumption of the each house, provide of the surplus power behavior boundary conditions of the activities of agent, and the way how to install the power exchange station such as the number power exchange station and the location of power exchange station, and it is difficult to find good design which is the combination of the conditions. Furthermore, in order to design social system considered every day of people behavior, we propose a new method for evaluating the value of the system design to obtain a better society, by massive simulation based on simulating the agent of individual the behavior.

3.2 Why MASim is needed

In the previous section, in order to validate the proposed system, it is described to use the MASim. In this section, at the beginning, we introduce what is MASim, and what MASim can be done. Next, we summarize the characteristics of the new system, and discuss why MASim is necessary, by showing that MASim are suitable for the new system.

MASim is a simulation model individually agent behavior as a principal, and calculate the chain of interaction of people and organizations. MASim is suitable for following situation.

- Multi-agent simulation is suitable for expression of the society form a number of people.
- Multi-agent simulation is suitable represent heterogeneity and diversity of actors.

Generally, there are two approaches for social system till now. First, approach to use multi-agent simulation for understanding of social phenomena and analysis of the social system. Secondly, approach to use multi-agent simulation for preverification social institution or new system.

Meanwhile, there are two characteristics of the new system as following description.

- Complex massive social system

  The new system is configured based on the existing transportation system, and the power system. That is to say, it is necessary to adjust a wide variety of system conditions for a new system to combine the existing systems. Moreover, it is possible that a lot of EV and PV users in existing system will join in the new system, and a huge number of people behave by their own decision-making, become an important component of the system.
- Interaction in the system

  Human behaviors, and decision-making, which are important component of the system, change the behavior of the system dynamically. Since the result based on a number human behavior, it is difficult to understand the reason the change brought. There is a mutual influence between human behavior in the system and system conditions, and human behaviors, decision-making flexibly change by the Environment being involved. Thus, if some the system requirements changed, somehow human behavior, decision-making will effect to system, eventually, it caused further change to the entire system.

From the point of view, mutual influence of energy and human behavior, energy can affect people's lives directly, and changes in conditions that can affect its impact by the people. MASim is useful when if you want to capture individual human behavioral changes, and by integrating human behavioral changes, understand the change in all. From another point of view, dynamic component of the system, e.g. it is all different that each energy consumption situation, individual situation like ownership of PV and EV individual behavior patterns. Thus, extremely complex situation was created. In that case, MASim is model individual actors as an agent causes the representation of the situation and observation can be easily achieved. Therefore, it obviously shows that Characteristics of two systems considered in this study match to the suitability of the MASim - MASim is suitable for the new system.

As already introduced, both the conventional two approaches, the purpose of the role of simulation was to reproduce the behavior. Based on simulation could be a tool of promote the dialog in order to design the unknown society system, in this paper, deploying candidate design of sustainable society on the simulation environment, for exploring the " the image " of appropriate social based on the results of interaction of a large number of virtual human beings (multi-agent). This paper take a unique approach to evaluating the as-is design that can realize the to-be system on the MASim, where MASim is used as an evaluation unit.

Chapter 4 Simulation Platform

In this simulation, it is implemented as an integrated simulation, including electrical distribution simulator and traffic simulator based on massive multi-agent simulator [4]. Our research team, so far, implemented a simulator based on the architecture of urban transport simulation platform [27, 28]. The PV power distribution integrated EV system simulation in urban city is based on following simulation platform. On traffic simulation, traveling route calculation included make a stop by power exchange station, and reproduction of driving operation was calculated for each agent. On power distribution simulation, the amount of system power cost, the amount of PV generation, the amount of power consumption when EV run or cost in house. Both traffic simulation and power distribution simulation are run by the simulation platform at the same time.

4.1 Simulation Platform Overview

In our previous work considers that agents in the traffic simulation should be covered by flexible combinations of various decision-making models. This is because agents face various situations and make decisions according to their current situations while they move around the city. In addition, the simulation has to include traffic systems such as traffic control systems and car navigation systems. The platform must integrate various aspects of the city environment.

Figure 5 shows the architecture proposed in this paper. This architecture includes multiple simulators and each simulator captures a specialized aspect of the traffic domain (e.g. route selection aspect and driving behavior aspect). Settings unique to the environment covered by each simulator and the environment settings shared by the simulators are input. When the result of a certain simulator influences another simulator, the result is stored in the shared environment. On the other hand, information that is unique to one simulator cannot be accessed by other simulators. Such data is accumulated in the corresponding local environment. Simulation controller should manage the simulation processes in order to combine the multiple simulators. The controller requests simulators to

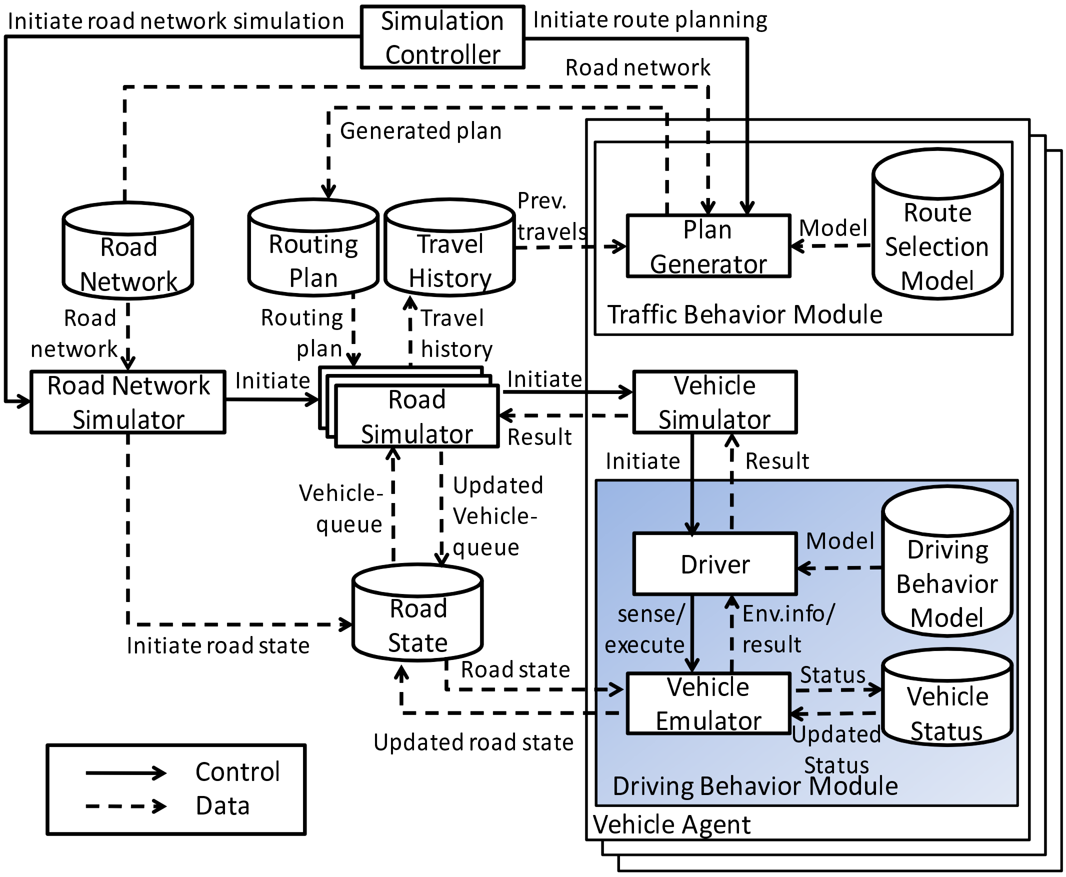


Figure 5: Architecture for Multi-model Simulation Platform

calculate the state of the next step. Basically, the simulators receive a request to output a result for the next time step. When an event that should be sent to another simulator occurs in the calculation, the event is sent to that simulator through the simulation controller.When all simulations finish, the logs of local environments and the logs of the shared environment are written to external files.

4.2 Module Function

There are three module in our simulator for global traffic: Route Selection Module, Route Execution Module, Driving Behavior Module.

The route selection module reads road network data and OD (Origin-Destination) data of agents from the shared environment. Road network data mainly describes the structure of the road network while the OD data consists of tuples of the starting point and the destination point of each agent.The road network has travel times of each link; this paper use either initial default values or the results of the traffic flow simulation of the previous day. The route selection module calculates the average trip time of each road based on the traffic information of the previous day.In the route selection module, an agent is regarded as the entity performing route selection. The agent selects the route that has minimum cost considering map information and the average trip time of each road. A route plan consists of paths, mode choice, daily activity, and so on.

The route execution module deals with abstracted road networks, not two-dimensional spaces. The route execution module is implemented for handling a queue-based simulator; that is, the road network is represented as a network of FIFO (First-In, First-Out) queues. Each agent moves over this queue-network between queues according to its scheduled routing plan given vacancies in the next queue. Traffic flows in this platform are composed of agent transfers between queues.The route execution module reads the route plan of each driver agent from the shared environment. In the route execution module, the agent is regarded as the plan executor.
The road network is abstracted as a network consisting of nodes and links. The agent acquires location information on the basis of nodes and links. A road node pops a driver agent from the waiting queue and pushes it onto the running queue of the next road link, if the running queue on the next road link has enough space.

In order to achieve traffic simulations that cover the driving behavior level, this paper add a driving behavior module. In the driving behavior module, the agent is regarded as a virtual driver and vehicle. They move in a two-dimensional space rather than the abstract road network.The driving behavior module starts calculating driving behavior when an agent enters a link in the route execution module. The module reads agent ID and road ID from the shared environment and gets details of the road 's structure and surrounding environment including neighboring vehicles from the road module in the local environment.

4.3 Simulation Controller

The simulation controller administers the entire simulation process. Simulator communication is based on message passing. At the beginning of a city traffic simulation, the route selection module is called to create a route from starting point to goal point for each agent. After that, the traffic simulation is started. The route execution module is called every second to calculate the route traces of agents on the abstracted road network.

Figure 6 shows how the simulators work together by sending messages.

When a simulation is started, the controller requests the route selection module to calculate a route from starting point to goal point (“ Next Day ”).When congestion occurs on an intersection, the route selection module receives a“ Congestion ”message from the route execution module and rerouting is begun. The route selection module returns“ Finish selection ”message. After that, the controller sends “ Load route ” to the route execution module which triggers the module into reloading the appropriate routes.

When the route execution module receives“ Next time ”message, the module calculates the state expected at the next time step. If the route execution module receives “ Enter node ” message which is raised by the “ Leave link ” message sent by the driving behavior module, the route execution module registers the agent mentioned in the message as an object to calculate the route trace of the agent on the road network. The agents on the route execution

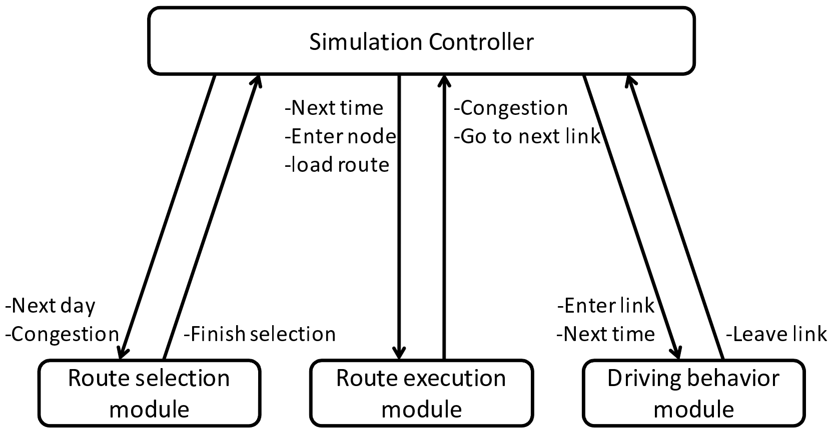


Figure 6: SimulatorControl

module decide the next link toward their goals and send “ Go to next link ” messages with agent ID and road ID to the simulation controller.

When the driving behavior module receives “ Next time ” message, the module calculates the state expected at the next time step. If the driving behavior module receives “ Enter link ” message which is raised from “ Go to next link ” from the route execution module, the driving behavior module registers the agent mentioned in the message as an object to calculate its driving behavior. The driver agents in the driving behavior module check whether they have reached the end of the link or not. If they have arrived at the end of the link, “ Leave link ” messages are sent to the route execution module via the simulation controller. In this manner, our platform for traffic simulations can integrate the simulators that reflect different aspects of driving in a city, i.e., global route planning execution and local reactive behavior.

Chapter 5 Approach: Good Design Search and Evaluation based on MASim

In this chapter, the approach -design search and evaluation based on MASim details- was showed with following five sections, the whole picture of the approach proposed in this paper. In section 5.1, the overview of the approach was described. In section 5.2, power distribution model was defined. In section 5.3, the simulation parameters were defined. In section 5.4, the applied search algorithm for good design search was discussed. In section 5.5, the function for evaluation to simulation results was defined. At last, section 5.6 shows the process for finding good design.

5.1 Approach Overview

In this paper, a new supporting approach proposed for system design which combines the good design search by search algorithms and the evaluation on the MASim environment, to make a decision, which is difficult to make by human, multiple condition defining the behavior of complex system. More specifically, first, modeling target system and defining evaluation function, based on attribute variables to representing the characteristics of the social system, and possible variable value, the quantitative value represent desirability of social system need to design was calculated. Secondly in order to find the good design(the good solution), the evaluation process, which can summarized as create candidate design, input parameter set in simulation, and evaluate the simulation result, and the process will be iterated for finding good design until search algorithm find the solution is the most higher evaluation value based on MASim.

5.2 Definition of Power Distribution Model

In Figure 4, the model which input and output of power at facility and agent, in the PV power distribution simulation, can be considered. Figure 7 shows the model of input and output at facility (artificial building) such as house, power exchange station. At facility, the power for charging EV, the power consumed by electronics, from the power from PV system generated, and lead from system power or facility battery. It is always possible to use the system power, so, facility battery only storage the PV power or discharged power from EV. If the power in facility battery was no enough, because of charging EV, consumption of facility, system power will be used, of course, facility battery become full and surplus PV power created, the reverse power flow to power system occurs. However, power exchange station as one kind of facility, doesn't have the function to generate PV power. The PV power cannot all consumed, can storage in facility batteries, and consumed by facility when necessary. That means, facility batteries also function as a buffer for making more efficient use of PV power.

Figure 8 shows the power model of input and output on EV. On EV, when traveling, the power from car battery is consumed by car motor. When parking at the facility, the power is derived from facility to car battery, if necessary. If facility battery didn't have enough power from providing, the power will directly derive from the power system.

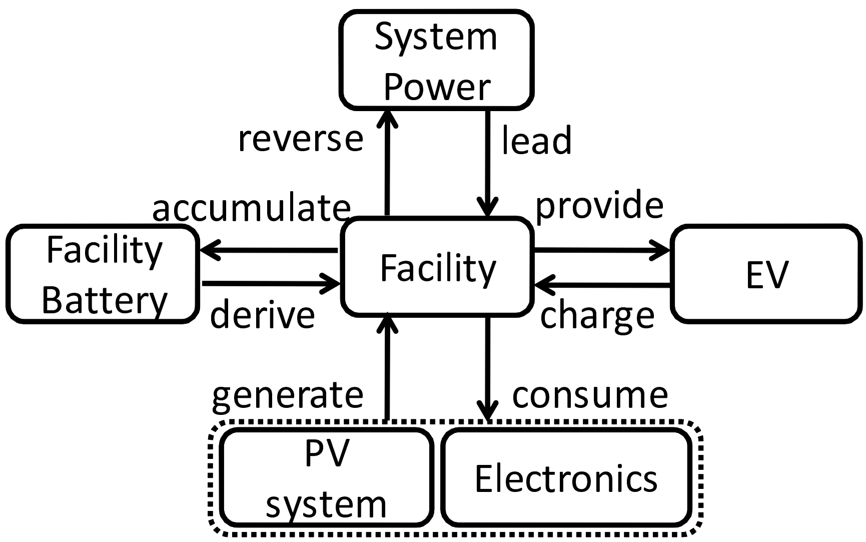


Figure 7: Facility Power Model

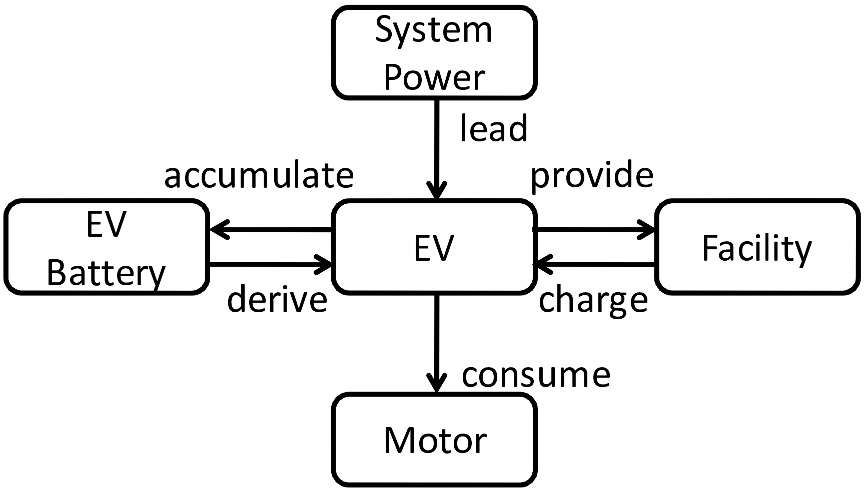


Figure 8: EV Power Model

5.3 Simulation Parameter Condition

In this simulation, agents decide their own action, and execute activity of traveling, energy consumption, " giving-and-taking " energy, based on simulation parameter condition. Moreover, this simulation assumed that agent which simulate the EV's behavior, will cooperate the action about " giving-and-taking " energy, based on making sure the power was enough to consume, and calculate the amount of system power leaded and amount of Reverse PV power during the simulation. In this paper, solar energy distribution system, defined by more than one parameter, such as equipment in the system and human behavior, is the concrete design target. Also the parameters do not exist in the proposed system, because the proposed system is unknown. So when simulation parameter conditions were decided, which describe the proposed system on the simulation, there is not a lot of information can be considered. Moreover, when a designer designs a new social system, it is also a big issue to find a suitable parameter from so many kind of candidate parameter for functioning well and safe. Therefore, This paper experimentally suggest the simulation parameters, based on proposed system in Chapter 3.

The parameters shows in Table 5, Both the parameters setting and the

Table 5: Simulation Parameter Condition

Parameter List	**Details**		
Rate of PV Spread	25 %		
PV Placement Pattern	equally installed by region		
Participation Rate of New System	20 %	40 %	60 %
Acceptable Range of the Distance to Station	500m	1000m	2000m
Number of Station	40	60	80
Station Placement Pattern (Inner City: Peripheral Part: Suburban)	1:1:3	1:3:1	3:1:1

domain definition were described [1]. However, in order to force on validation of solar energy distribution system, this paper assume that the system environment already cable to distribute the PV power as PV power generation has become a level of popular. Further, this paper classified city space into three parts: Inner City; Peripheral Part; Suburban, and allocate three parts to three zones as a concentric circle based on the distance of the center of the city. As following, Zone 1, 2, 3 each means Inner City, Peripheral Part, and Suburban.

1. Rate of PV Generator Spread

   This is a parameter to decide how many facilities have PV generator, and also decide the amount of PV power to social system. This paper set the rate of PV generator spread with 25% as a static value, for assuming the system environment already cable to distribute the PV power.

2. PV Generator Placement Pattern

   This is a parameter to decide the rate of PV generator placement in each city zone, and also one of the parameter decides the location of PV Generator. In this paper, there is no bias of the installation by region, more specifically; the rate is 1: 1: 1 in zone 1, 2, and 3.

3. Participation Rate of New System

   This is a parameter to decide how many EV users will cooperate with proposed solar energy distribution system, and decides the potential amount

[1] About parameter condition, the Kyoto City was assumed

of PV power distribution. In this paper, the parameter is set as 20%, 40%, 60%.

4. Acceptable Range of the Distance to Station
   This is a parameter to decide the area of user behavior, which joins the proposed solar energy distribution system. More specifically, the parameter decide upper limit of the distance to power exchange station, deviating from the optimal original traveling route, in order to provide the surplus power. In this paper, the parameter is set as 500m, 1000m, and 2000m.
5. Number of the Power Exchange Station
   This is a parameter to decide the accumulated amount of surplus PV power. However, power exchange station only exist in proposed system, that means the number of power exchange station is not easy to decide, so the number charging infrastructure: 88[1)] was used as reference. In this paper, the parameter is set as 40, 60, and 80.
6. The Placement Pattern of Power Exchange Station
   This is a parameter to decide the placement rate of power exchange station in the zone, and also decides the location of collection and distribution of PV power. The location of power exchange station affects each human behavior that joins the proposed. In this paper, the parameter is set as 3: 1: 1, 1: 3: 1, 1: 1: 3, of which is the rate in zone 1, 2, and 3.

In this simulation, there are more parameters can be involved; however, it is possible lead the space of solution become too expanded. This paper aim to focus on discusses the possibility of the approach of social system design based on MASim. So, we kept relatively small numbers of parameters, which are already decided above.

5.4 Search Algorithm

In order to find the good design of new social system was intended in this paper, the result is the combination of the individual parameters described in the previous section. Each parameter has been defined as social system condition,

1) At the end of July 2011. `http://www.pref.kyoto.jp/denkizidousya/resources/1313462870292.pdf` (2011).

and finds the conditions that set of values, which create more socially desirable behavior, is the purpose of calculation.

Considering previous discussion about the new system characteristic in chapter Chapter 3, the solution space is big, and interdependent relationship is involved. It is hard to calculate a strict solution. Therefore, this paper attempt to apply approximate search based on genetic algorithm[29].

Based on [30], Genetic Algorithms (GAs) are adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and genetics. As such they represent an intelligent exploitation of a random search used to solve optimization problems. Although randomized, GAs are by no means random, instead they exploit historical information to direct the search into the region of better performance within the search space. The basic techniques of the GAs are designed to simulate processes in natural systems necessary for evolution, and especially those follow the principles first laid down by Charles Darwin of " survival of the fittest. " Since in nature, competition among individuals for scanty resources results in the fittest individuals dominating over the weaker ones. It is better than conventional AI in that it is more robust. Unlike older AI systems, they do not break easily even if the inputs changed slightly, or in the presence of reasonable noise. Also, in searching a large state-space, multi-modal state-space, or n-dimensional surface, a genetic algorithm may offer significant benefits over more typical search of optimization techniques.

Solution candidate $\vec{d_i}$ related to social system design as a gene, virtual social system based on enclosed gene information was deployed on simulator, and simulation was executed. Fitness of gene was decided by emergent phenomenon and its evaluation, and new design gene is created by crossover and mutation following the process of genetic algorithm. Through iteration of the same progress, it is possible that find a useful design for any social system.

There are some related work attempt solve complex problem based MASim. In [31], they propose a method of problem solving negotiating to assume a nonlinear utility space, but have solved the difficulty of finding the solution in multidimensional space utility, the evaluation value of the candidate solution, and utility value of the constraint can be satisfied can be easily calculated by summation. However in this paper, the evaluation value of solution candidate $\vec{d_i}$ can be calculated for the first time, through the emergence of large-scale phenomenon based on the interaction of agent. Thus, it is possible solve the problem, which both discovery and evaluation is difficult.

Through the progress, which describe the detail in this section 5.6.

- Create gene（candidate design）.
- Input gene in simulation.
- Evaluate the simulation result.

The higher value of solution is searched. Each attribute C_i is represented C the set of (conditional) attribute, defined the behavior of social systems as a target system. Each C_i take any number of values, and referred to $C_i = \{v_{i1}, v_{i2}, \cdots, v_{ij}\}$. Solution candidate is represented as vector of the value assigned to each $\vec{d_i} = (v_{i1}, v_{i2}, \cdots, v_{|C|})$. MASim calculate agent behavior based on any solution candidate $\vec{d_i}$, the set of agent A as a input. Thus, the action decision under the virtual social environment on the basis of individual agent $a_k \in A$ behavior model and its execution is repeated set the environment (based on virtual environment $\vec{d_i}$) of simulation based on $\vec{d_i}$. The simulation result is evaluated based on evaluation function, and the calculation is continued by using the new solution candidate nearby $\vec{d_i}$(or the progress of calculation stop by the end conditions).

5.5 Evaluation Function

In order to evaluate the simulation result using the parameter condition, the function of evaluation is necessary. The social indicator (fitness) was calculated, based on simulation result. This paper use an indicator (R) as the ratio of the amount of PV power consumption accounts for the total power consumption. Specifically, as the following formulas:

$$R = \frac{PV PowerConsumption}{TotalPowerConsumption} \tag{1}$$

$$
\begin{aligned}
PVPowerConsumption &= PVPowerGeneration \\
&\quad -TotalReversePowerFlow \\
&\quad -EVConsumption
\end{aligned} \tag{2}
$$

In Formula 1, the indicator (R) is calculated. Since the indicator (R) is defined as the ratio of the amount of PV power consumption accounts for the total power consumption, obviously, the indicator (R) is the proportion of the PV Power Consumption percentage of Total Power Consumption. The Total Power Consumption is calculated by collecting the all Power Consumption from all EVs and facilities, which are simulated in proposed system, based on the definition of power distribution model. The PV Power Consumption is calculated by Formula 2. Thus, based on Formula 1 the closer the calculation result of indicator (R) is to " 1 " the better the system design is going to be, and it also means the better value that the system design brought to the social system. As formula 2 shows the PV Power Consumption is calculated by three elements, which are PV Power Generation, Total Reverse Power Flow, and EV Consumption, based on the definition of power distribution model. The PV Power Generation is the amount of generated PV Power, collecting from each facility such as home and supermarket. The Total Reverse Power Flow is the amount of reversed power collecting from each facility. The EV Consumption is the amount of consumption for traveling. This paper assume a large enough percentage effect social power to move the society to be covered by a large PV power, and socially preferable that as the value of the (R) and closer to a total quantity of electricity savings, power use by an effective PV.

5.6 The Process for Finding Good Design

In order to find good design, the gene was created, which encode from the each parameter as introduced, in the first place. Each parameter combined in gene, which means a defined condition in the proposed system. The purpose of calculation is to find the set of condition value produce more socially desirable behavior. The most important point of this progress is possible evaluate any

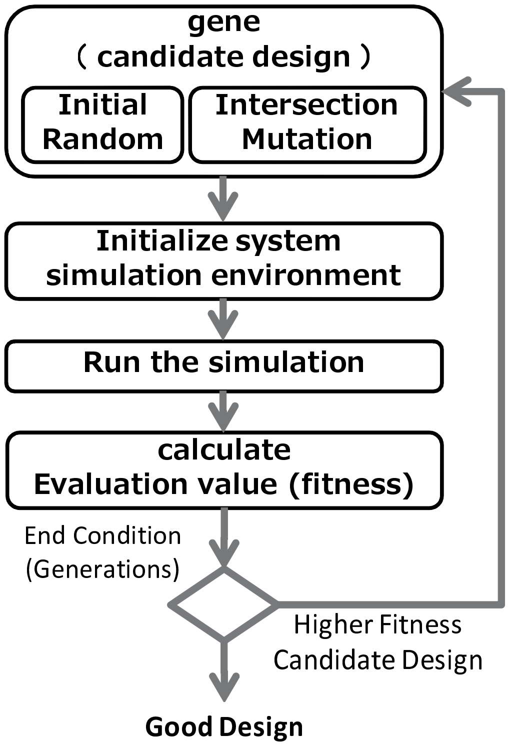


Figure 9: Calculation Process

evaluation of social system design without proposed system, by integrating the behavior (agents) of a large number of virtual human beings, based on using MASim as fitness function on genetic algorithm.

Moreover, in Figure 9, the calculation process consists of seven steps as below.

1) Initialing several gene randomly.

2) Initializing system simulation environment based on enclosed genetic information

3) Running the MASim.

4) Calculating the the social indicator(fitness), based on simulation result.

5) Handling parents gene from selection, crossover, and mutation based on fitness, a new candidate set as new system design added.

6) Returning the good design, if satisfying the exit condition(e.g. Generation number).

7) If it is not go back to 2).

There is an attempt of Kurahashi et al [32], that applies the genetic algorithm to MASim. However, in this paper, a reverse simulation approach is proposed, which a virtual environment represented by MASim, and creates results that match the real social indicators. Further, with evolved virtual environment agent, if the results match the real social indicators will be attempted. In this case, the agent can evolve a genetic algorithm, configure the artificial society, with social indicators match will be attempted. They share certain similarities point in that set the social indicators point to update the components of the MASim by evolutionary computation. However, in order to achieve a result that asymptotically in reality, the nature of the agent is updated real social phenomenon, also has the purpose of understanding of social interaction, especially in the electronic society. Moreover, in the paper purpose was to obtain a valid design of unknown social system. It is a technique will evolve the environment surrounding the agent, the nature of which has fixed as each one has individual behavior model. Thus it is different in both purpose and method.

Chapter 6 Experiment

In this chapter, it showed that how the multiple conditions mentioned in the last chapter applied to create a calculation method by combining a multi-agent simulation and a search algorithm.

6.1 Setting

For the experiment, this paper used an actual Kyoto City transportation network as the model for Kyoto City network. Using a 20km$\times$2 area emanating from downtown Kyoto as a base of operations, this paper chose approximately 50,000 links and 100,000 nodes from a digital topographical map-published by Zenrin-to employ in my model road network. this paper also ran 10,000 agents along this network that mimicked their real-life counterparts in Kyoto. For the agents' routes, this paper based them on a Person Trip Survey (20,000 OD) that was conducted in the year 2000.

As for the parameters for PV-powered electric vehicles, this paper based them on Energy White Papers [1)]. While all PV-power generators possess the exact same attributes, this paper did not factor in weather conditions. Therefore, the amount of power generated by such vehicles daily always conforms to the same standard.

6.2 Results

Figure 10 shows the amount of photovoltaic power produced and the amount of electricity purcvhased under the optimal combination of the following variables– in other words, properties that would yield the highest R values within this hypothetical society relying upon city-operated, PV-powered electric vehicles: rate of participation in the system, maximum willing travel distance of subjects, the number of recharging stations, and placement patterns. The X-axis represents a 24-hour time period and the Y-axis represents the amount of power produced in kilowatts. Furthermore, Figure 11 displays a comparison bewteen the solu-

1) METI: White Paper on Energy, Available from: `http://www.enecho.meti.go.jp/topics/hakusho/2010/index.htm` (2010).

tion from Figure 10 and a different one regarding the amount of photovoltaic electricity purchased.

As previously mentioned, all PV-power generators possess the same attributes, and therefore all produce the same amount of electricity. However, the amount of electricity received from units differs. As evinced by Figure 10, under favorable conditions, the increase/decrease in power produced and the amount purchased behave almost identically. Also, before peak hours-during the morning-over half the available electricity was used effectively. Even as peak hours passed in the afternoon, the amount of PV electricity received from units–which had been stored during peak hours-was kept relatively low. On the other hand, under unfavorable conditions, large amounts of electricity are received from home units during peak hours, causing even the electricity sent to homes to be returned.

Furthermore, the amount of electricity purchased from home units in Figures 10 and 11 are $1298kWh$and $2111kWh$ respectively. By comparing the two amounts, this paper can deduce that choosing a better effective system can improve its effectiveness by up to 40%. Also, for Figure 10, This paper set the parameters mentioned earlier in this chapter at $60\%, 2000m, 60, 1:1:3$. Parameters for Figure 11 were set at $20\%, 500m, 40, 3:1:1$. This paper gathered many participants who agreed to travel long distances and This paper set most of the recharging stations in the downtown area of the city in order ro reduce the number needed, which helped produce the possibility of a favorable outcome mentioned previously.

With only this data in mind, it cannot be determined that collecting PV-power from EVs and the distribution of recharging stations exhibited any effects. Therefore, I compared the amount of electricity received from EVs by individual recharging stations, the result of which is shown in Figure 12. If the amount of electricity sent from the units was relatively small, (Generous Case), that meant that the recharging stations were mostly receiving electricity. As the transition on the graph suggests, the amount of electricity collected was highest during the day when most people are active, as well as during the hours of 5 p.m. to 9 p.m.–when most people return home from work. However, if the amount of

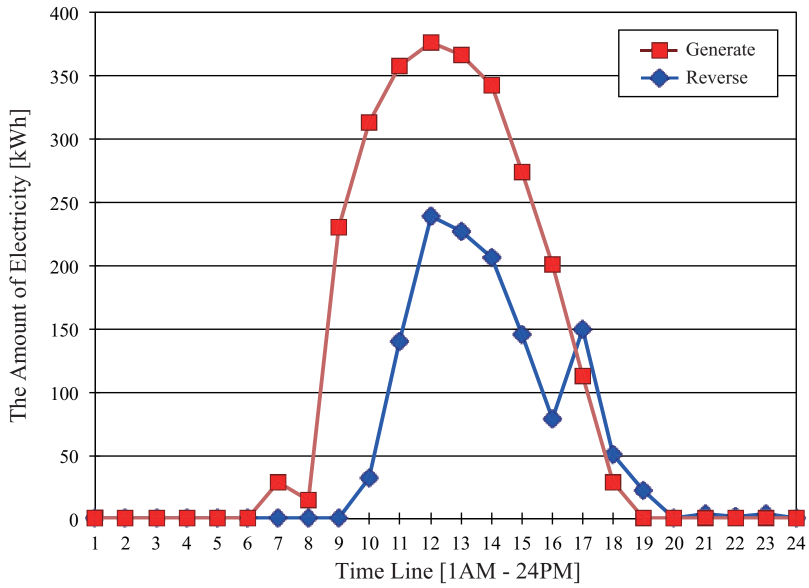


Figure 10: High Score Case

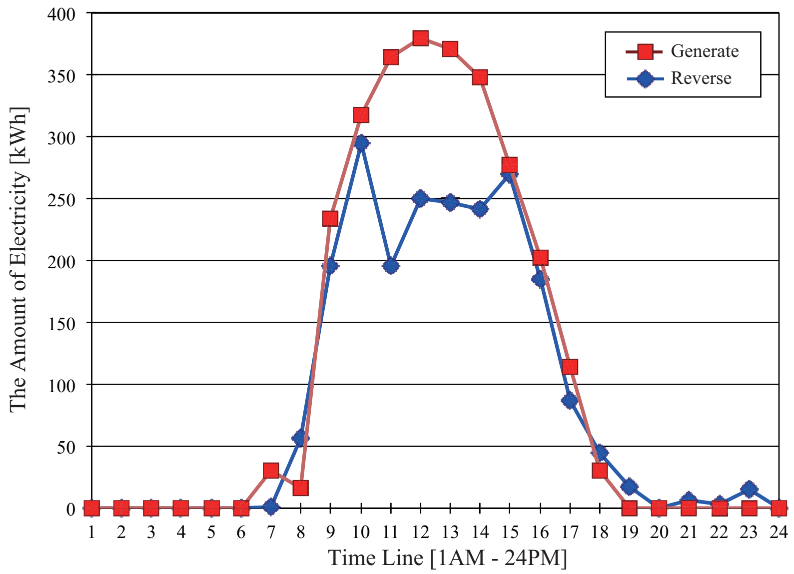


Figure 11: Low Score Case

electricity sent from the units was relatively large (Stingy Case), it could be inferred that not much electricity was collected during the day and the amount of visits to the recharging stations was relatively few, due to the need to provide electricity.

Moreover, the total amount of electricity exported by the units was $501kWh$

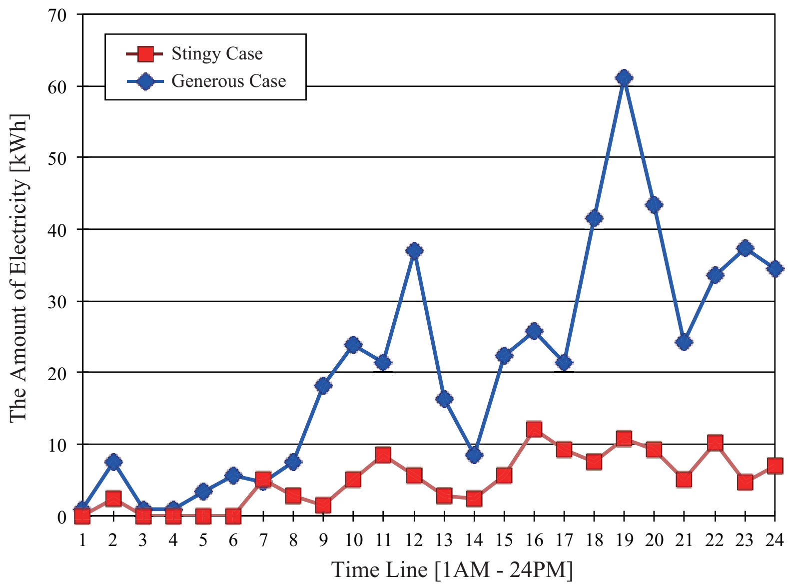


Figure 12: Surplus Power Flow at Station

in the Generous Case, and $118kWh$ in the Stingy Case, which is a perceivable difference. For example, if the amount of electricity sent from recharging stations to the EVs were $9863kHw$, that would mean the amount of electricity provided would be approximately 5%. However, it is safe to assume that the cause of this is due to the simulation restricting agents' activity to one trip (Home → Workplace → Home) per day. Therefore, it is obvious that the simulation needs to be further refined in order to produce even more accurate data.

The combination of certain algorithms can give us insight into heretofore unknown social systems and allow us to predict properties of them using certain indexes.

6.3 Discussion

Based on experiment results, the good design is {60%, 2000m, 60, 1:1:3}, which means the participation rate of new system PV is 60%, the acceptable range of the distance to station is 2000m, the number of the power exchange station is 60, and the placement pattern of power exchange station is 1:1:3. This is also a result about the interaction between agent and environment. If classified the parameters as follows:

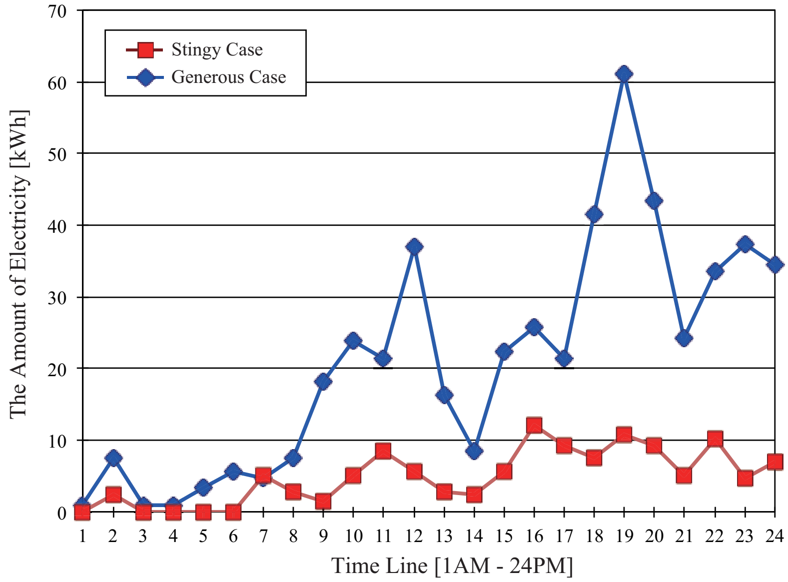
- The parameter define agnet:
  participation rate of new system PV, acceptable range of the distance to station.
- The parameter define environment:
  number of the power exchange station, placement pattern of power exchange station.

As already described, this simulation involved agent behavior model decides how each agent behaves, based on other agent, or system environment. Thus, the good design as an experimental result describes the consequence of interaction between agent behavior and system environment.

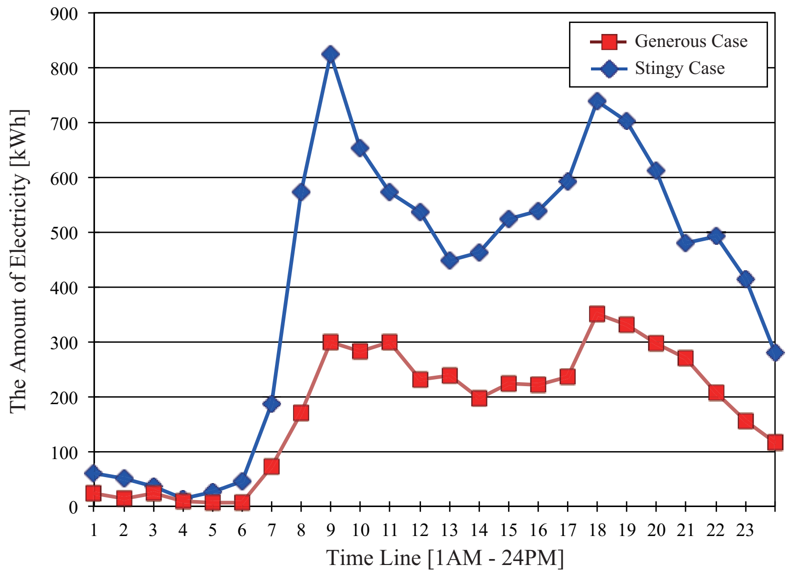
In this paper, despite execute the same simulation with the same system design, there is no guarantee that the same result can be calculated. In Figure 13 there are two different results: Case A and Case B, which show the collecting PV-power from EVs using the same simulation with the same system design. In case A(Figure 13a), as the transition on the graph suggests, the amount of electricity collected was highest during the day when most people are active, as well as during the hours of 5 p.m. to 9 p.m.–when most people return home from work. In case B (Figure 13b), as the transition on the graph suggests, the amount of electricity collected was highest during the day when most people are active, as well as both during the hours of 5 p.m. to 9 p.m.–when most people return home from work and during the hours of 7 a.m. to 10 a.m.–when most people go to work.

Moreover, the amount of collecting PV-power from EVs in case B more than case A. The result occurred because two reason as follows:

- Agent behavior changes dynamically
  Each agent travels based on their own the model of behavior. Moreover, when traveling, such as change the travel route the action changes, based on system environment such as departure, destination, and the distance to power exchange station. It causes a chain of interaction between agents dynamically. Therefore, despite execute the same simulation with the same system design, the result is different based on agent behavior changes dy-



(a) Low case



(b) High case

Figure 13: Different results based on same parameter set

namically.

- Interaction between agent behavior and simulation parameter
  Simulation parameters affect the agent behavior. In this paper, the accurate location of power exchange station was decided randomly, based on

placement pattern instead of decide the accurate location of power exchange station at the first place. The system environment changes based on random location, and the agent also changes the behavior such as starveling route. Therefore, despite execute the same simulation with the same system design, the result is different based on simulation environment, which is decided by ambiguity simulation parameter.

In this paper, the termination condition of the proposed simulation is 30 generations. The score of system design did not show a convergence trend. However, it is necessary stop the experiment, because the larger amount of computation request long calculation time. So it is only a small part of solution space that evaluated system design. Generally, it is difficult that discover a gene can easier converge with high probability in the early stage of calculation because the number of generation for evaluate is small. Moreover, considering the proposed system is a complex massive social system, the solution space is extremely large. Thus, even use the approximate search algorithm, the larger number of generation for calculation is required. Moreover, the size of the solution space cannot advance at the first place, because the calculated design, which is for construct an uncertain social system, is searched. Therefore, it is difficult that estimate the execution time of the simulation, which decide by the number of calculated generation until the convergence trend was confirmed.

Chapter 7 Conclusion

7.1 Accomplishment

In the past few years, the research of MASim 's has been applied to various fields. Typically MASim was used to simulate the behaviors of a social system which is too complex to understand and predict. This research explored the feasibility of applying MASim to design a social system as a assistant tool.

It is very difficult to design a social system appropriately due to the increasingly complexness of human society. Human behavior changes frequently and unexpectedly with continually updating new technologies and social structures. Thus, it becomes much more difficult to find a social system to control human behaviors appropriately. This research addressed the issue of designing the unknown social system, which exceeded the capacity of the human beings. We designed and created a virtual environment, and evaluated the simulation results using MASim under different conditions in this environment.

In this research, we proposed the system that combines the factors of transportation and electronic power, and built the environment on the simulation. However, our purpose is to assert that MASim can contribute to the globally important problem of designing social systems rather than implementing such systems in the real world. Moreover, the research on energy problem is becoming more and more important in recently years. Thus, the contribution of this research is considered as an important step in this area and expected to be applied to previous researches.[5, 21].

7.2 Future Work

In this section, there are two future work will be discussed. First, it is necessary to explore more efficient calculation method. Secondly, it should bring more interesting results, if expanded the simulation environment.

Exploring More Efficient Calculation Method

In this paper, despite execute the same simulation with the same system design, there is no guarantee that the same result can be calculated, based on the diversity of chain of the interaction of agents. Considering this feature It is possible contribute the generation of practical design more sophisticated, however, It cost more and more calculation make solving progress hard. At this stage, because the solution space is huge and its distribution is non-linear, the genetic algorithm was employed as an example. As a future work, it is necessary to explore more efficient calculation method.

Expanding the Simulation Environment

In this paper, the production of PV power was kept in the same level, in order to focus on find the good design on proposed system. In reality, the production of PV power is unstable, because the feature of PV energy. Therefore, it is interesting that verify the relationship between unstable PV power and system behavior, based on proposed system.

in order to achieve that it is necessary that add a new model to calculate the production of PV power, by considering the feature of energy production side such as weather conditions, amount of solar radiation, solar radiation time. The parameters were classified in two kind of class.

- simulation parameter:
  weather conditions, amount of solar radiation, solar radiation
- calculation coefficient of system:
  Coefficient of performance power generator (Panel capacity, area, and angle of installation)

Thus, the relationship is created between two kind parameters, such as unstable PV in each individual home, weather conditions, amount of solar radiation, and solar radiation, and system parameter, based on proposed system. Further, It can be expected that volume-up scenario, which can be verified based on variations in the amount of electricity production by PV and discovery knowledge based on reproduction of relations of production and consumption.

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Appendix

This appendix show the details about parameter set used in simulation, and the parameter set can be classified in two classes as follows:

Common elements between all parameter sets

- GO_ENE_00: Base power value(w) to go to power station
  The bigger the value is, the less possibility go to power station
- EV_CON_xx: EV consumption ($kwhperhour$)
  xx show the types.
- EV_PRO_x: EV transmission efficiency ($kwhperhour$)
  xx show the types.
- EV_CHA_xx: EV transmission efficiency ($kwhperhour$)
  xx show the types.
- HOME_BAT_TYPE_xx: MAX_VOL, MIN_VOL, INIT_VOL
  Home battery's capacity, maximum value, minimum value, the initial value.
  xx show the types.
- HO_GEN_xx: Home power generation efficiency
  Home power generation efficiency for each time zone
- HO_GEN_xx: Home power consumption(kwh)
  Home power consumption for each time zone(1 hour)

Different elements between all parameter sets

- id: simulation parameter set' ID
- Population: The number of EV
  The number of EV = The number of active agent = The number of home
- EV_PRO_xx: Transmission efficiency from facility to EV(kw)
  For home use the number directly, for power station 30 times before use xx show the types.
- GO_DIS_xx： Acceptable range of the distance to station(Represent as simulation unit)
  Range of the Distance to Station, it is necessary convert to meters． xx show the types.
- HO_FAC_xx： PV power generation performance at home(kw)

The amount of PV power generation calculated from " ability × efficiency × time ", xx show the types.

- ACT_TYPE_xx: Sojourn time
  The time agent spent on destination, xx show the types.
- MAX_BATTERY_TYPE_xx: Maximum cumulative dosage(kwh)
  xx show the types.
- R_element name_xx: The rate ate of each element
  e.g. 「R_HO_FAC_00=20.0, R_HO_FAC_01=60.0, R_HO_FAC_02=20.0」 shows the rate of HO_FAC_00 is 20%, HO_FAC_01 is 60%, and HO_FAC_02 is 20%.

Based on above definition, parameter set sample describe as follows:

```
ParamSet = (id=4958579419894109
    Param = {ACT_TYPE_AM_00={ACT_TYPE_AM_00=1.0}
        ACT_TYPE_AM_01={ACT_TYPE_AM_01=8.0}
        R_ACT_TYPE_AM_00={R_ACT_TYPE_AM_00=70.0}
        R_ACT_TYPE_AM_01={R_ACT_TYPE_AM_01=30.0}
        ACT_TYPE_PM_00={ACT_TYPE_PM_00=1.0}
        ACT_TYPE_PM_01={ACT_TYPE_PM_01=8.0}
        R_ACT_TYPE_PM_00={R_ACT_TYPE_PM_00=30.0}
        R_ACT_TYPE_PM_01={R_ACT_TYPE_PM_01=70.0}
        R_PV_TYPE_PAID={R_PV_TYPE_PAID=80.0}
        R_PV_TYPE_NOT_PAID={R_PV_TYPE_NOT_PAID=20.0}
        HO_FAC_00={HO_FAC_00=0.0}
        HO_FAC_01={HO_FAC_01=10.0}
        HO_FAC_02={HO_FAC_02=15.0}
        HO_FAC_03={HO_FAC_03=20.0}
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        R_HO_FAC_02={R_HO_FAC_02=0.0}
        R_RULESET_TYPE_00={R_RULESET_TYPE_00=100.0}
        R_RULESET_TYPE_01={R_RULESET_TYPE_01=0.0}
        R_RULESET_TYPE_02={R_RULESET_TYPE_02=0.0}
```

```
        MAX_BATTERY_TYPE_00={MAX_BATTERY_TYPE_00=20.0}
        MAX_BATTERY_TYPE_01={MAX_BATTERY_TYPE_01=50.0}
        MAX_BATTERY_TYPE_02={MAX_BATTERY_TYPE_02=100.0}
        R_MAX_BATTERY_TYPE_00={R_MAX_BATTERY_TYPE_00=20.0}
        R_MAX_BATTERY_TYPE_01={R_MAX_BATTERY_TYPE_01=60.0}
        R_MAX_BATTERY_TYPE_02={R_MAX_BATTERY_TYPE_02=20.0}
        POPULATION={POPULATION=9000}
        GO_DIS_00={GO_DIS_00=2000}
        EV_CHA_00={EV_CHA_00=1.0}
        R_HAS_PV_ZONE_0={R_HAS_PV_ZONE_0=34.0}
        R_HAS_PV_ZONE_1={R_HAS_PV_ZONE_1=33.0}
        R_HAS_PV_ZONE_2={R_HAS_PV_ZONE_2=33.0}
        HAS_HOME_BATTERY={HAS_HOME_BATTERY=0.0}
        STATION_NUM={STATION_NUM=80.0}
        R_LOCATE_STATION_ZONE_0={R_LOCATE_STATION_ZONE_0=20.0}
        R_LOCATE_STATION_ZONE_1={R_LOCATE_STATION_ZONE_1=20.0}
        R_LOCATE_STATION_ZONE_2={R_LOCATE_STATION_ZONE_2=60.0}
    }
)
```