IAC Network for Composition of Waste-Incineration Facility

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Abstract: This research explores a prototypical interactive activation and competition (IAC) network to facilitate the selection of an appropriate facility combination for municipal solid waste incineration on the basis of characteristics of waste streams. Waste of types treatable with a specific facility combination was also evaluated. A prototypical IAC network was developed with a knowledge base constructed from five data sources: waste characteristics, air-pollution–control devices, pretreatment units, flue gas cooling types, and combustion-chamber types. Unlike a traditional database or a rule base, questions with incomplete information can be answered by the IAC network. This advantage greatly helps an engineer screen a sound facility combination for a specified waste stream with some degree of uncertainty. The prototype can be used also by a waste authority to preliminarily evaluate waste facility construction permit applications, by a novice engineer to learn the appropriate usage of a facility, and by an incinerator manager to preliminarily evaluate treatable waste.

INTRODUCTION

The success of a waste incinerator relies on an appropriate selection and combination of incineration facilities, including pretreatment units, combustion chamber, flue gas cooling devices, and air-pollution–control equipment, on the basis of characteristics of waste streams to be incinerated. After selection and composition of appropriate facilities, the incinerator manager needs to know also what types of waste are treatable by the incinerator. This information is especially important for an incinerator operated in a private sector to provide appropriate services to its consumers. Officers in local environmental protection agencies in Taiwan have responsibility of preliminary review of waste incinerator construction permit applications but generally lack training of incinerator design. This research was thus initiated to develop a prototypical interactive activation and competition (IAC) network to facilitate facility selection and composition related tasks. The network is also expected to be able to help a novice engineer to learn the appropriate usage of a facility.

Information stored in an IAC network is distinct from that stored in a traditional database. Searching through a traditional database for information, a designer must provide data that match exactly, partly or completely, the data stored in the database. If the designer provides incomplete data, the database typically responds with null information. Furthermore, the information obtained from a traditional database does not indicate the correlation level associated with the designer-provided data. For a municipal solid waste incinerator design problem, the exact final solution cannot be immediately known before exploring many possible alternative facility combinations. A traditional database, although valuable, may be less helpful than an IAC network during a design searching session. An IAC network can provide information correlated to the designer provided data, which may include information incomplete or having some degree of uncertainty.

IAC NETWORK

An IAC network is a simple neural network. It had been applied for visual word recognition (McClelland and Rumelhart 1981; Rumelhart and McClelland 1982), machine-part classification (Moon 1990), and dynamic control (Goodall and Raggia 1990). Grossberg (1978) provided a mathematical introduction of an IAC network. A brief description of the theory of the network is provided in the following. A more detailed description of the theory can be found in many books on neural networks such as by Rumelhart et al. (1988).

An IAC network, as shown in Fig. 1, is constructed by several competitive data pools with network links connecting the competitive nodes in the same pool and correlated nodes in separate data pools. The links are divided into two categories: inhibitory and excitatory. An inhibitory link connects competitive nodes within the same data pool to avoid multiplying activated nodes in the same pool, and an excitatory one connects correlated nodes in separate pools to activate related nodes in these separate pools. With such a setup, the node with strongest activation tends to deactivate the other nodes in the same pool and highly correlated nodes in separate pools would be activated. The activation levels of nodes indicate the degree of correlations between activated nodes and simulated input nodes. The mathematical implementation of such a network is described in the following.

The net received activation (inhibitory or excitatory) level of a node is computed according to the following equation:

$$NET_i = \sum_j W_{ij} OUTPUT_j + EXINPUT_i$$

where NET_i = activation level of node i; W_{ij} = weight (strength) of link between node j and i; $OUTPUT_j$ = activation level of node j; and $EXINPUT_i$ = externally provided activation. The activation level of a node is then altered by an amount ΔA_i that is determined according to the following rule.

If $NET_i > 0$, $\Delta A_i = (MAX - A_i)NET_i - DECAY(A_i - REST)$;

otherwise $\Delta A_i = (A_i - MIN)NET_i - DECAY(A_i - REST)$

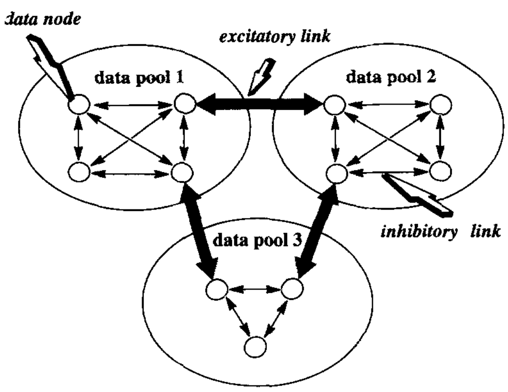

FIG. 1. IAC Network

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where *MAX*, *MIN* = parameters for maximal and minimal activation levels, respectively; *DECAY* = parameter for activation decay rate, generally between 0 and 1; *REST* = parameter for rest level, generally between *MIN* and 0; and A_i = current activation level.

With continuous activation, the network typically reaches an equilibrium state. The activation competition of nodes within the same data pool is judged by their activation/inhibitory strength. For example, assume that there are two nodes, a and b, in a data pool that receives excitatory inputs, E_a and E_b, respectively. Then, the net received activation levels for a and b are

$$NET_a = E_a - r(OUTPUT_b)$$

$$NET_b = E_b - r(OUTPUT_a)$$

where r = inhibitory strength between nodes a and b.

The node receiving a larger initial activation tends to inhibit the other node. For example, if $E_a > E_b$, node a inhibits b more than b inhibits a, and gradually node a becomes the dominant node and node b is not activated as much as node a.

MSWIFS NETWORK

The network structure of the developed prototypical municipal solid waste incineration facility selection (MSWIFS) network is shown in Fig. 2 and the knowledge database used for this prototypical network is summarized in Table 1. The knowledge base used for the prototypical MSWIFS network extracted from Kiang (1982), Kiang (1983), and Niessen (1978) includes five data sources: waste stream characteristics, pretreatment units, combustion chamber types, air-pollution control devices, and flue-gas cooling equipments. Thirteen data pools are built within the network:

- 1a. phase: solid type 1 (SOL1), solid type 2 (SOL2), liquid (LIQ), sludge type 1 (SLU1), sludge type 2 (SLU2). Solid type 1 is for bulky waste. Sludge type 1 is for sludge which is transportable by a pipe.
- 1b. size distribution: uniform particle size (PARU) and nonuniform particle size (UPAR).
- 1c. heating value: high heating value (HHV) and low heating value (LHV).
- 1d. acid: high acidity (HACD) and low acidity (LACD).
- 1e. ash: high ash content (HASH) and low ash content (LASH).
- 1f. ash melting point: high ash melting point (HMAH) and low ash melting point (LMAH).
- 1g. water content: high water content (HWC) and low water content (LWC).
- 1h. heavy metal: volatile heavy metal (VHM) and nonvolatile heavy metal (NVHM).
- 1i. flash point: high flash point (HFSP) and low flash point (LFSP).
- 2. combustion chamber: mechanical grate (GRAT), rotary kiln (RKIL), fluidized bed (FBED), multiple chamber (MCHM), and liquid injection (LQIN),
- 3. cooling: boiler cooling (BOIL) and water spraying cooling (SPWA).
- 4. pretreatment: mixing (MIX), crushing (CRUS), and drying (DRY).
- 5. air pollution control device: scrubber (SCRU) and dust removal (DUST).

An instance hidden pool was added for each data pool as the intermediate pool to transfer the activation/inhibition signals input by the user or triggered by other related inhibitory/excitatory nodes. Although the LWC, NVHM, and LFSP lack links to nodes in other data pools, their inhibitory connections with nodes in the same pool can prohibit the selection of facilities for HWC, VHM, and HFSH.

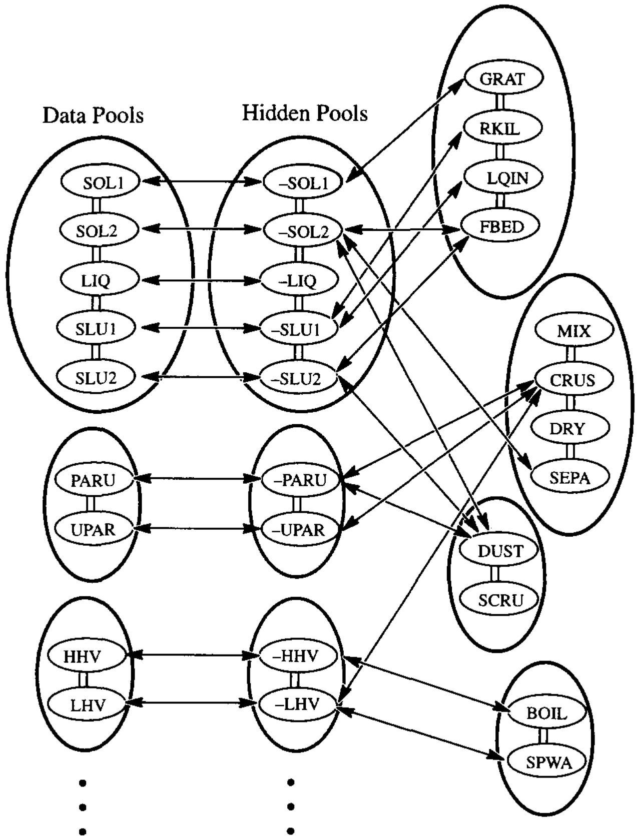

FIG. 2. Prototypical MSWIFS Network

TABLE 1. Correlated Data Used to Construct Prototypical MSWIFS Network

Waste characteristics (1)	Combustion chamber (2)	Cooling type (3)	Pretreatment type (4)	Air pollution control device (5)
SOL1	GRAT	—	—	—
SOL2	FBED	—	CRUS	DUST
LIQ	LQIN	—	—	—
SLU1	FBED	—	—	DUST
SLU2	RKIL	—	—	—
PARU	FBED	—	—	DUST
UPAR	RKIL	—	CRUS	—
HHV	—	BOIL	MIX	—
LHV	—	SPWA	MIX	—
HACD	—	SPWA	MIX	SCRU
LACD	—	BOIL	—	—
HASH	MCHM	—	—	DUST
LASH	—	BOIL	—	—
HMAH	RKIL	—	—	DUST
LMAH	−FBED	—	—	—
HWC	—	SWPA	DRY	SCRU
LWC	—	—	—	—
VHM	—	—	—	DUST
NVHM	—	—	—	—
HFSH	—	—	MIX	—
LFSP	—	—	—	—

IMPLEMENTATION AND TEST RESULTS

The prototypical MSWIFS network was built and implemented with the *Iac* program developed by McClelland and Rumelhart (1989). The initial state of the network is shown in Fig. 3, in which no activation has been stimulated. The number

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before each node name is the external excitation level (initialized to zero) and the number after is the final state of the node (initialized to -0.1). The final state number is expressed as percentage and thus -0.1 is expressed as -10. External excitation is implemented by stimulating the desired node with the value 1.0, which is indicated by a '**' in the following figures. Three demonstration cases were implemented for the MSWIFS network, described as follows.

```
0 GRAT -10 0 MIX  -10 0 SOL1 -10 0 HASH -10 0 _SOL1-10 0 _HASH-10
0 RKIL -10 0 CRUS -10 0 SOL2 -10 0 LASH -10 0 _SOL2-10 0 _LASH-10
0 FBED -10 0 DRY  -10 0 LIQ  -10 0 HMAH -10 0 _LIQ -10 0 _HMAH-10
0 MCHM -10            0 SLU1 -10 0 LMAH -10 0 _SLU1-10 0 _LMAH-10
0 LQIN -10            0 SLU2 -10 0 HWC  -10 0 _SLU2-10 0 _HWC -10
                      0 PARU -10 0 LWC  -10 0 _PARU-10 0 _LWC -10
                      0 UPAR -10 0 VHM  -10 0 _UPAR-10 0 _VHM -10
0 BOIL -10 0 DUST -10 0 HHV  -10 0 NVHM -10 0 _HHV -10 0 _NVHM-10
0 SPWA -10 0 SCRU -10 0 LHV  -10 0 HFSP -10 0 _LHV -10 0 _HFSP-10
                      0 HACD -10 0 LFSP -10 0 _HACD-10 0 _LFSP-10
                      0 LACD -10            0 _LACD-10
```

FIG. 3. Initial State

Case 1: Waste Characteristics

In this case, the MSWIFS network was tested to find an appropriate facility combination for a waste stream with waste characteristics of solid type 2 (SOL2), uniform particle size (PARU), high heating value (HHV), high acidity (HACD), and volatile heavy metal (VHM). According to Fig. 4 fluidized bed (FBED), spray water (SPWA), mixing pretreatment (MIX), and dust removal (DUST) are activated, after the MSWIFS network is stabilized. This facility combination is suitable to treat the specified waste stream.

```
0 GRAT -17 0 MIX   60 0 SOL1 -18 0 HASH  23 0 _SOL1-19 0 _HASH 43
0 RKIL -12 0 CRUS  -9** SOL2  80 0 LASH -13 0 _SOL2 60 0 _LASH-16
0 FBED  57 0 DRY  -14 0 LIQ  -18 0 HMAH  23 0 _LIQ -19 0 _HMAH 43
0 MCHM -12            0 SLU1 -16 0 LMAH -13 0 _SLU1 35 0 _LMAH-20
0 LQIN -17            0 SLU2 -18 0 HWC   15 0 _SLU2-19 0 _HWC  32
                     ** PARU  80 0 LWC  -12 0 _PARU 64 0 _LWC -14
                      0 UPAR -18** VHM   80 0 _UPAR-17 0 _VHM  56
0 BOIL  -8 0 DUST  72** HHV   79 0 NVHM -18 0 _HHV  47 0 _NVHM-17
0 SPWA  51 0 SCRU -15 0 LHV  -16 0 HFSP  20 0 _LHV  32 0 _HFSP 39
                     ** HACD  80 0 LFSP -13 0 _HACD 62 0 _LFSP-15
                      0 LACD -18            0 _LACD-17
```

FIG. 4. Case 1: Waste Characteristics

Case 2: Facility

Other than finding an appropriate facility combination for a specified waste stream, the MSWIFS can be used also to find appropriate treatable waste streams for a specified facility combination. For example, in Case 2, a rotary kiln (RKIL) incinerator with mixing treatment (MIX) and spray water (SPWA) facilities was tested. The characteristics of treatable waste streams, based on activated nodes in the MSWIFS network result shown in Fig. 5, is sludge type 2 (SLU2), nonuniform particle size (UPAR), low heating value (LHV), high acidity (HACD), high ash content (HASH), high ash melting point (HMAS), high water content (HWC), volatile heavy metal (VHM), and high flash point (HFSP).

Dust removal equipment (DUST) was also activated in this case. This result reminds the designer to add dust removal equipment for the specified facility combination. This function is useful for a designer to design a complete facility combination, for facility reviewers of an environmental authority to screen a waste incineration proposal, and for a novice engineer to learn how to lay out a complete design.

```
 0 GRAT -19** MIX   83 0 SOL1 -14 0 HASH  14 0 _SOL1-16 0 _HASH 31
** RKIL  83 0 CRUS -15 0 SOL2 -14 0 LASH -12 0 _SOL2 -9 0 _LASH-14
 0 FBED -19 0 DRY  -15 0 LIQ  -14 0 HMAH  30 0 _LIQ -16 0 _HMAH 58
 0 MCHM -16            0 SLU1 -14 0 LMAH -14 0 _SLU1 -9 0 _LMAH-17
 0 LQIN -19            0 SLU2  25 0 HWC   25 0 _SLU2 47 0 _HWC  47
                       0 PARU -14 0 LWC  -14 0 _PARU -9 0 _LWC -16
                       0 UPAR  25 0 VHM   14 0 _UPAR 47 0 _VHM  31
 0 BOIL -18 0 DUST  49 0 HHV  -13 0 NVHM -12 0 _HHV   9 0 _NVHM-14
** SPWA  83 0 SCRU  -8 0 LHV   32 0 HFSP  25 0 _LHV  62 0 _HFSP 47
                       0 HACD  32 0 LFSP -14 0 _HACD 63 0 _LFSP-16
                       0 LACD -14            0 _LACD-17
```

FIG. 5. Case 2: Facility

Case 3: Incomplete information

The MSWIFS network can be used also to answer questions with incomplete information. For example, a fluidized bed (FBED) incinerator generally requires dust removal air pollution control devices. If only FBED (fluidized bed) and CRUS (crushing) are specified, a traditional database may be unable to provide appropriate information for such incomplete information. The MSWIFS network, however, can supplement with some appropriate information. The DUST node is significantly activated, as shown in Fig. 6, although it is not initially specified and activated. The characteristics of SOL2, SLU1, PARU, HASH, HMAH and VHM for treatable waste streams are also activated for this incomplete information set.

```
 0 GRAT -17 0 MIX  -17 0 SOL1 -14 0 HASH  23 0 _SOL1-19 0 _HASH 44
 0 RKIL  -3** CRUS  81 0 SOL2  29 0 LASH -12 0 _SOL2 66 0 _LASH-14
** FBED  83 0 DRY  -17 0 LIQ  -14 0 HMAH  23 0 _LIQ -19 0 _HMAH 44
 0 MCHM -12            0 SLU1  15 0 LMAH -12 0 _SLU1 51 0 _LMAH-19
 0 LQIN -17            0 SLU2 -14 0 HWC  -10 0 _SLU2-19 0 _HWC -10
                       0 PARU  31 0 LWC  -10 0 _PARU 59 0 _LWC -10
                       0 UPAR -10 0 VHM   23 0 _UPAR 21 0 _VHM  44
 0 BOIL -10 0 DUST  73 0 HHV  -10 0 NVHM -12 0 _HHV -10 0 _NVHM-14
 0 SPWA -10 0 SCRU -16 0 LHV  -10 0 HFSP -10 0 _LHV -10 0 _HFSP-10
                       0 HACD -10 0 LFSP -10 0 _HACD-10 0 _LFSP-10
                       0 LACD -10            0 _LACD-10
```

FIG. 6. Case 3–1: Incomplete Information (I)

Another sample is shown in Fig. 7 in which only high acidity (HACD) waste characteristics and mixing (MIX) pretreatment type are activated initially. Scrubber (SRUB) and spray water (SPWA) cooling type are then activated because they are related to high acidity waste characteristics. Subsequently, the nodes of low heating value (LHV), high water content (HWC), and high flash point (HFSP) are also activated. Although high heating value is linked to MIX, it is deactivated by LHV, which obtains stronger activation signals from MIX and SPAW nodes.

```
0 GRAT -10** MIX   83 0 SOL1 -10 0 HASH -10 0 _SOL1-10 0 _HASH-10
0 RKIL -10 0 CRUS -19 0 SOL2 -10 0 LASH -10 0 _SOL2-10 0 _LASH-10
0 FBED -10 0 DRY  -15 0 LIQ  -10 0 HMAH -10 0 _LIQ -10 0 _HMAH-10
0 MCHM -10            0 SLU1 -10 0 LMAH -10 0 _SLU1-10 0 _LMAH-10
0 LQIN -10            0 SLU2 -10 0 HWC   25 0 _SLU2-10 0 _HWC  47
                      0 PARU -10 0 LWC  -14 0 _PARU-10 0 _LWC -16
                      0 UPAR -10 0 VHM  -10 0 _UPAR-10 0 _VHM -10
0 BOIL -16 0 DUST -14 0 HHV  -12 0 NVHM -10 0 _HHV  12 0 _NVHM-10
0 SPWA  59 0 SCRU  25 0 LHV   30 0 HFSP  25 0 _LHV  57 0 _HFSP 47
                     ** HACD  80 0 LFSP -14 0 _HACD 66 0 _LFSP-16
                      0 LACD -18            0 _LACD-17
```

FIG. 7. Case 3–2: Incomplete Information (II)

With this function, a designer can facilitate the design tasks by prescreening some inappropriate waste streams. A novice engineer can also play what-if questions with the network to realize the interrelation strength of various design attributes.

CONCLUSION

The prototype MSWIFS network stores data in a way distinct from that of a traditional database. The network can respond to questions with incomplete information and the degree of relationship between the response and provided information. During a designing stage, numerous possible alternatives should be explored before a sound design can be prepared. A designer, however, generally lacks appropriate tools to help him/her to do so and thus some inadvertent mistake may be made or some creative good designs are not explored. The correlation level of activated information to the designer-specified information reported by the network can help a designer to screen alternatives or to modify his/her design to meet various requirements.

The prototypical MSWIFS is expected to be used for a designer to explore various alternatives, for waste authority to review a waste facility construction permit application, and for a novice engineer to practise selection of appropriate equipment. The prototype will be extended by adding more detailed design information and by testing it by a design office during continuing research.

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