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A System Dynamics Approach for the Determination of Adverse Health Impacts of Healthcare Waste Incinerators and Landfill Sites on Employees

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Abstract

The risks associated with the treatment and disposal of healthcare wastes has gained attention across the world over last decades. The potential for a causal link between the hazardous emissions from waste treatment facilities and certain adverse health outcomes in workers employed in these facilities is difficult to prove or to supply with decent figures.

However it is required to have a mechanism which provides an approach and data to assess this risk in order for the justification of selection and planning of any waste treatment system.

In order to derive usable estimates for the adverse health impacts on workers, a system dynamics approach was adopted by using a software package, Vensim Ple Plus. Using relative risks and latency periods of adverse health outcomes reported by the epidemiological studies and the incidence rates from Turkish Health Statistics for Istanbul, Turkey, the hospital admissions (morbidity) is expected to increase by 40.0% and 9.3% among landfill and incinerator workers respectively over the 30-year employment time; while mortality rate

goes up by 0.4% in landfill employees and 0.6% in incinerator employees over the same period of employment.

Keywords: Healthcare waste; Hazardous emissions; Waste treatment facilities; Adverse health outcomes; Decision making; System dynamics approach.

1. Introduction

The risks associated with healthcare waste and its management has gained attention across the world over last decades and this has resulted in the increased recognition of a need for proper healthcare waste management. The primary objective of managing waste, healthcare waste is no exception, is that the materials should be handled, treated and disposed of safely. In this respect, The UK Health Department (UK DoH 2011) categorises treatment methods of healthcare wastes in two groups; (1) High temperature (incineration) technology and (2) Non-burn/low temperature alternative technologies (pre-treatment) and then disposal of to landfill [the EU Landfill Directive (European Union 1999) prohibits landfilling of healthcare waste without pre-treatment]. It is stated by the Department that while anatomical waste (18-01-02), healthcare chemicals (18-01- 06*[(1)]), pharmaceuticals (18-01-09 or cytotoxic and cytostatic medicines 18-01-08*) must only be treated by incineration; the others [such as swabs, soiled dressings and gloves (orange bag 18-01-03*)] can also be treated by various alternative technologies and then disposed of to landfill (Bracketed numbers are from the European Union Waste Catalogue 2000).

Landfilling and incineration of solid waste releases toxic substances. Because of the wide range of pollutants and different pathways; long term exposure concerns remain about potential health effects. Much of the current understanding of the health impacts of the healthcare waste treatment technologies is based on epidemiology. This paper aims to provide an overview of the current epidemiologic studies reporting health impacts of healthcare waste treatment technologies (landfill and incineration), and to determine the additional cases of workers due to the exposure of hazardous emissions in their working place.

2. Literature Review

The main pathways of exposure were identified in the literature as inhalation, consumption of water, and the food chain (Table 1 identifies the source-pathway-receptor relation of landfill and incineration). However the studies surveying the emissions to land or water are very limited in number, while there are a number of studies in the literature which provide information on emissions to air from waste treatment facilities. Defra (2004a) states that this does not mean that health effects due to exposure via water or soil are less significant; however, there are controls on food and water quality which make any exposures through these pathways easier to avoid. Therefore inhalation of emissions is the pathway which is mostly assumed by epidemiological studies.

[1]: The European Union Waste Catalogue 2000 is divided into 20 chapters. Each chapter is represented by a two-digit code between 01 and 20 and comprises one or more subchapters (Chapter 18 is for healthcare wastes). Individual waste types are detailed in the subchapters and are assigned a six-digit code that comprises two digits for the chapter, two for the subchapter and two specific to the waste type. Hazardous wastes are signified by

entries where the EWC code is marked by an asterisk (*).

Table 1. Emission-Pathway-Receptor for Landfill and Incineration

	Source (Emissions)		Pathway	Receptor
Landfill	Air	Landfill Gas (CO_2, CH_4 and numerous trace compounds), exhaust gases from combustion of landfill gas, dust and odour	Emissions of fugitive landfill gas and products of landfill gas combustion	Nearby sensitive receptors
	Water	Leachate containing salts, heavy metals, biodegradable and persistent and synthetic organic compounds	Leachate run off to water sources	Users of water resources (groundwater or surface water)
	Soil	Metals (Zn, Pb, Cu, As) and various organic compounds	Land contamination during post-operative activities, animal factors (seagulls, vermin, rats) and visual effect	Post operative site users
Incineration	Air	SO_2, NO_x, N_2O, HCl, HF, VOCs, CO, CO_2 emissions, dioxins and furans, metals (Zn, Pb, Cu, As), dust, odour, micro-organisms and PAHs	Emissions of gases and particles from combustion of waste	Nearby sensitive receptors
	Water	From deposition of combustion gases: sulphuric, carbonic and nitric acids, particulate matter, metals (Zn, Pb, Cu, As), dioxins and furans	Deposition of hazardous substances to water resources	Receptors in the vicinity of waste water treatment plants
	Soil	From ash and combustion gases: metals (Zn, Pb, Cu, As), dioxins and furans, sulphuric, carbonic and nitric acids, particulate matter, fluoride and chloride	Leaching of materials from landfilled ash; and deposition of combustion gases	Receptors exposed to contaminated soil

Much of the current understanding of the health impacts due to the healthcare waste treatment technologies is based on epidemiological studies. Giusti (2009) categorises these studies into three groups:

(1) Prospective Cohort Studies: Two cohorts of people (exposed and non-exposed) who differ with respect to certain factors under study are followed over a period to determine how these factors affected rates of a certain outcome. This kind of study generally involves the collection and analysis of blood or tissue samples. For example: Unuvar et al. (2007) conducted a survey to assess whether pregnant women were at risk of mercury intoxication due to fish consumption by taking blood samples from mothers and their new born babies.

Mudge et al. (2011) described the prevalence of inadequate energy and protein intake in older inpatients by screening consecutive patients admitted between November 2007 and March 2008 to the Royal Brisbane and Women's Hospital in Australia. Likewise Hoek et al. (2002) examined the association between mortality and indicators of traffic related air pollution in the Netherlands by investigating a random sample of five thousand people from 1986 to 1994. A similar study was conducted in China by Cao et al. (2011) to improve understanding of the link between outdoor air pollution and mortality.

On the other side, having too many repeated measurements and the selection of the measurement time points of cohort studies cause these studies to have an ad-hoc basis according to Tekle et al. (2011) who pointed out the necessity of optimal design methods with a controlled budget for these studies.

(2) Retrospective Case-Control Studies: A case group of people who have already developed a specific disease, and a control group of healthy people are selected. Information on past exposure is collected retrospectively, generally via interviews with the participants. These studies are relatively inexpensive compared to prospective cohort studies as (A) they involve smaller groups of people, (B) they do not generally require structured experiments, but are more prone to bias (Giusti 2009). For instance: The study by Burke and Sawchuk (2003) was based on 244 women who died from tuberculosis between 1874 and 1884. Some 12% of them had given birth within the year preceding their death. The study used the records in the local government death registries; and indicated that recent childbirth did not increase the risk of tuberculosis mortality among these women.

(3) Cross-Sectional Studies: They take account a specific group of the exposed population over a short period of time. They are 'cross sectional' because data is collected at one point in time. They can only be useful to generate hypotheses that can be tested later by more comprehensive studies; otherwise they might not be effective at distinguishing whether a particular disease developed before or after the group was exposed to a potential hazard as they do not look at time trends. There are a number of examples of cross-sectional studies in the literature as they are relatively cheap to carry out (Mino et al. 2001; Peabody et al. 2006; Scheeres et al. 2008; Geldart et al. 2010).

In order for the definition of the strength of the association between exposure to a potentially toxic substance and specific health effects in epidemiological studies, the ratio of the incidence of a disease in the exposed population to the incidence of the same disease in the non-exposed population is calculated; this is called "Relative Risk" (RR) or "Odd Risk" (OR). For instance, if the RR is 6, the risk is six times higher (or an increase of 500%) in the exposed population than that in the non-exposed population.

The studies which were evaluated in this research were selected accordingly to the criteria proposed by Hester and Harrison (2002): (1) They have to be conducted in authorised incinerations or landfills; meaning that the ones considering open burning or unregulated disposal sites were disregarded; (2) They must provide some degree of consistency with other different epidemiological studies in terms of the types and significance of the outcomes; (3) They must have a theoretical basis in linking adverse health effects and exposure pathway;

and (4) They must have a basis for the effects, as indicated by actual measurements or examinations.

The number of the studies satisfying the criteria set by Hester and Harrison (2002) is very study: Gelberg (1997) carried out a cross-sectional study to examine acute health effects among employees working for the New York City Department of Sanitation. Landfill workers reported a significantly higher prevalence of work-related respiratory (RR=2.14), dermatologic (RR=2.07), neurologic (RR=1.89), gastrointestinal (RR=1.26) and hearing problems (RR=1.73), itching eyes (RR=1.54) and sorethroat (RR=2.26) than the controls.

Regarding the adverse health effects on incinerator workers, Gustavsson (1989) investigated mortality among 176 incinerator workers who were employed at least one year or more between 1920 and 1985 at a MSW incinerator in Sweden. Results revealed an excess mortality from cancer (oesophageal cancer RR=2.84; stomach cancer RR=1.27, rectal cancer RR=2.52, lung cancer RR= 3.55, bladder cancer RR=1.98, malignant cerebral tumors RR= 2.77, hematopoietic cancer RR= 1.35) and nervous disease (RR=1.33), circulatory disease (ischemic heart disease RR=1.38), respiratory disease (asthma, bronchitis, emphysema RR=1.62) and digestive disease (liver cirrhosis RR=4.54). The excess was found to be highest in workers with more than 40 years exposure.

Counter to the above study by Gustavsson (1989), a retrospective study on 532 workers employed at two municipal waste incinerators in Rome did not reveal any excess of lung cancer (Rapiti et al. 1997). Mortality from lung cancer was reduced in comparison to the general population and overall cancer mortality did not differ much from that of the general population. However it was noted a 2.79 fold increased risk of mortality from gastric cancer among workers who had more than 10 years latency since first employment.

A similar study was conducted by Hours et al. (2003); they carried out a cross-sectional morbidity study for 102 workers employed at three French incinerators during 1996, matched for age with 94 male workers from other industrial activities. The exposed workers were categorised into 3 exposure groups based their workplace: crane and equipment operators, furnace workers, and maintenance and effluent-treatment workers. The maintenance and effluent group encountered elevated relative risks for skin symptoms (RR=4.85). An excess of daily cough was reported for the maintenance and effluent group (RR= 2.55) and for the furnace group (RR=6.58).

Many epidemiological studies dealing with waste management report limitations regarding a lack of good exposure data and the use of surrogate indirect measures which might lead to exposure misclassification (Rushton 2003; Defra 2004a; Defra 2004b; Porta et al. 2009). One of the reasons for that is the unsuitableness of conducting an epidemiological study based on experiments (not on observations) for ethical reasons (Giusti 2009). It is clear that future research into the health risks of waste management needs to overcome these current limitations.

3. System Dynamics Modelling

Models represent some aspect of a real system which consists of several interrelated components and interactions among them. This real system could be a living space, a region or a city. Systems dynamics models are conceptual models focused on the selected parameters which have to be quantified as variables and their influences have to be formulated mathematically. Each arrow (Figure 1) indicates an influence of one element on another.

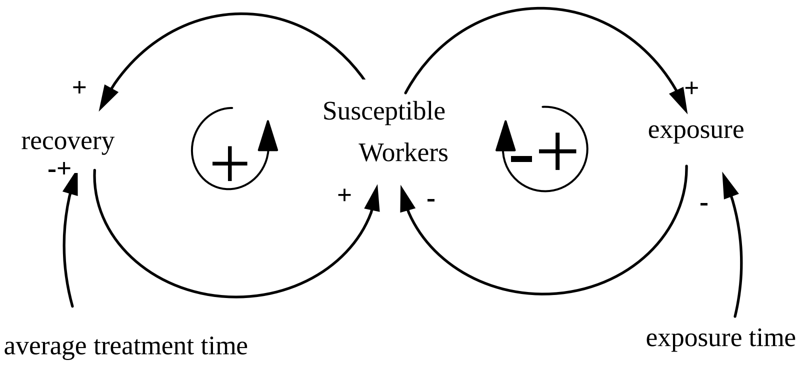

Figure 1. Causal Loop Diagram Notation

3.1 Causal Loop Notation

The word causal refers to cause-and-effect relationship and the word loop refers to a closed chain of cause and effect. The words (elements) represent the parameters in the system; and the arrows represent causal connections of these parameters.

Figure 1 shows the susceptible workers causal loop diagram. The diagram includes arrows linking the parameters together and signing either (+) or (–). These signs have the following meanings; (1) A causal link from one parameter to the other parameter has positive polarity (+); if the two parameters in a cause-and-effect relationship change in the same direction and (2) A causal link from one parameter to another parameter has negative polarity (–); if the two parameters change in opposite directions. In Figure 1, the positive polarity on the arrow between susceptible workers and recovery could mean that an increase in susceptible workers causes an increase in recovery or that a decrease in susceptible workers causes a decrease in recovery cases. Likewise in Figure 1, the negative polarity on the arrow between exposure and susceptible workers conveys the meaning of that an increase in exposure results in a decrease in susceptible workers and vice versa.

In addition to the signs on each arrow, a loop is given a sign. The dynamics of any system stem from the interaction of just two types of feedback loops; positive (or self-reinforcing) and negative (or self-correcting) loops. Specifically, (1) Positive loops tend to reinforce or amplify whatever is happening in the system. An initial disturbance in positive loops leads to further change by suggesting the presence of an unstable equilibrium and (2) Negative loops counteract and oppose the change. They tend to be self-limiting by seeking a balance or equilibrium.

3.2 Dynamics of Stocks and Flows

The parameters in systems dynamics models are categorised as stocks, flows, auxiliary variables, and arrows (Figure 2). Stock variables (symbolised as a rectangle) represent the accumulations in the system. Flow variables (valves) are the rate of the change in stock variables and they either fill in or drain the stocks depending on the activities they represent. Auxiliary/constant variables are intermediate variables used for miscellaneous calculations, and the arrows (connectors) are the information links representing the cause and effects within the model structure.

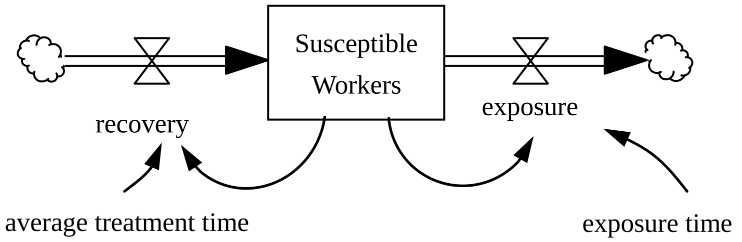

Figure 2. Stock and Flow Diagram

Mathematical Representation:

Integral equation: Susceptible Workers(t)=[recovery(s)−exposure(s)]ds+Susceptible Workers(to) (Eq.1)

Differential equation: d(Susceptible Workers)/dt=Net change in Susceptible Workers=recovery(t)−exposure(t) (Eq.2)

Notation used in the model: Susceptible Workers=INTEGRAL(recovery−exposure, Susceptible Workers(to)) (Eq. 3)

The Integral function is exactly equivalent to Eq.1 and represents that the stock (Susceptible Workers) accumulates its inflows (recovery) and discharges its outflows (exposure), beginning with an initial value of stock (Susceptible Workers). The mathematical mapping of a system occurs via a system of differential equations, which is solved numerically via simulation.

3.3 System Dynamics Modelling in Health Systems

The method has been applied widely in health systems as it offers diverse advantages over simple spreadsheet programs; such as it conceptualises and rationally analyses the structure, interactions and behaviour of complex systems to explore, assess, and prognosticate their impacts in an integrated, holistic manner (Kollikkathara et al. 2010); it facilitates a more sophisticated, quantitative simulation, hence it is capable of more robust and reliable outcomes (Wolstenholme 2005); and it is flexible enough to accept any adjustment which might be required under different conditions (Jian Li et al. 2008). It allows these adjustments to be implemented by fine-tuning the parameters.

Taylor and Dangerfield (2005) provided a plausible causal framework to present the interaction between bringing health services closer to the community and the improvements in accessing stimulating demand. Evenden et al. (2005) examined capturing Chlamydia infection within a population incorporating the behaviour of different risk groups in Portsmouth. In Canada, McGregor (2010) analysed jurisdictional conflict between a major and a minor healthcare profession by means of system dynamics. Furthermore Mothibi and Prakash (2006) presented an approach for the management of HIV/AIDS in order for the Bostwana Government to control the diseases.

Estimating atmospheric emissions from relevant sources is also a growing area of application. For example, Szarka et al. (2008) used system dynamics in conjunction with RegAir modelling technique and looked at emissions due to transport, energy consumptions etc. within the system boundary for the EuRegion Austrian-Hungary cross-border area. On the other side, Anand et al. (2006) presented a model based on dynamic interactions to estimate CO_2 emissions from the cement industry in India.

However the application of system dynamics in healthcare waste management has recently been introduced to the literature by two studies; (1) the research conducted by Chaerul et al. (2008) which analyses the effect of NIMBY (Not In My Back Yard) Syndrome on the healthcare waste generation; and (2) the research carried out by Ciplak and Barton (2012).

4. Development of Employees Health System Dynamics Model

The frequency of a number of incidences is higher among landfill and incinerator workers due to their exposure to hazardous emissions in their workplace compared to non-exposed societies as reviewed in the literature (Section 2). The models (Exposed Workers System Dynamics Model and Non-Exposed Workers System Dynamics Model) aim to estimate the number of "additional cases" which is expected to appear in 30-year-employment-time based on the data gathered from the literature survey.

The Exposed Workers System Dynamics Model (represented by Figure 3: Causal Loop Diagram of Exposed Workers System Dynamics Model and Figure 4: Exposed Workers System Dynamics Model) starts with the initial workers who have completed their exposure time period to develop the disease specified by the epidemiological studies. When the model is run, depending on the "average time to get infected" exposed-workers move to infected-workers stock. Based on average time for mortality, infected workers either die or recover and enter the susceptible workers stock. Exposure time introduces a delay for susceptible workers to reach to the certain level at which they start to develop symptoms of a disease.

The Non-Exposed Workers System Dynamics Model (Figure 5) aims to estimate the number of cases for the selected diseases that would appear in the same number of individuals (workers) in the same time period as Exposed Workers System Dynamics Model. This facilitates determining additional cases (additional hospital admissions and additional deaths) by subtracting the number of cases in exposed population from the number of cases in non-exposed population within the same amount of time. The number of additional cases refers to the number of workers whose poor health is due to the emissions from the waste treatment facility where they work.

Since initial workers are introduced to Exposed Workers System Dynamics Model as the exposed workers who have already completed an exposure time period, time period of both of the models was adjusted by subtracting the number of exposed years from 30-year-employment time (Figure 6).

The developed models were kept as simple as possible while capturing all necessary elements for the analysis of the system under study. The emphasis of the model was on structural and functional simplicity. These models are not comprehensive, and in such problems never will be, but are considered sufficient at this stage in terms of providing a basis for the purpose of the study in the light of reported cases in academic literature. However, these models could be improved by allocating disease specific parameters and could be adopted to solve similar problems (such as investigating of health impacts of hazardous emissions on public in the vicinity of waste treatment facilities); there are no doubt benefits to be achieved by further research into the characteristics of each specific diseases and the development of these diseases on populations.

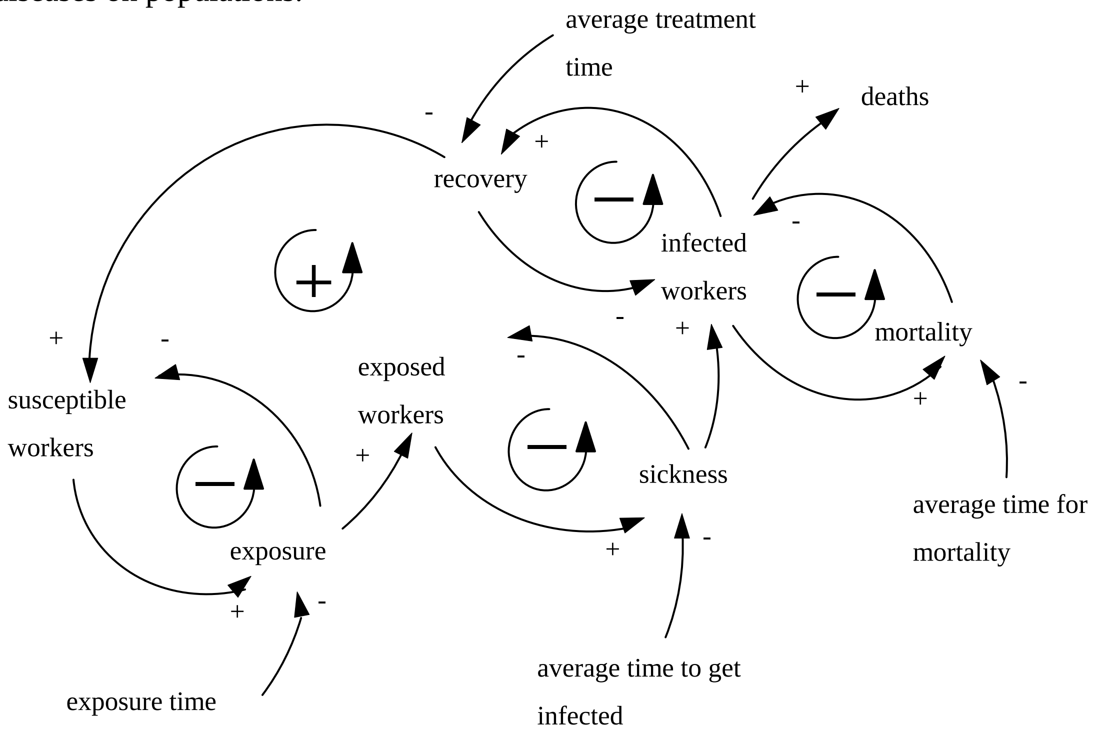

Figure 3. Causal Loop Diagram of Exposed Workers System Dynamics Model

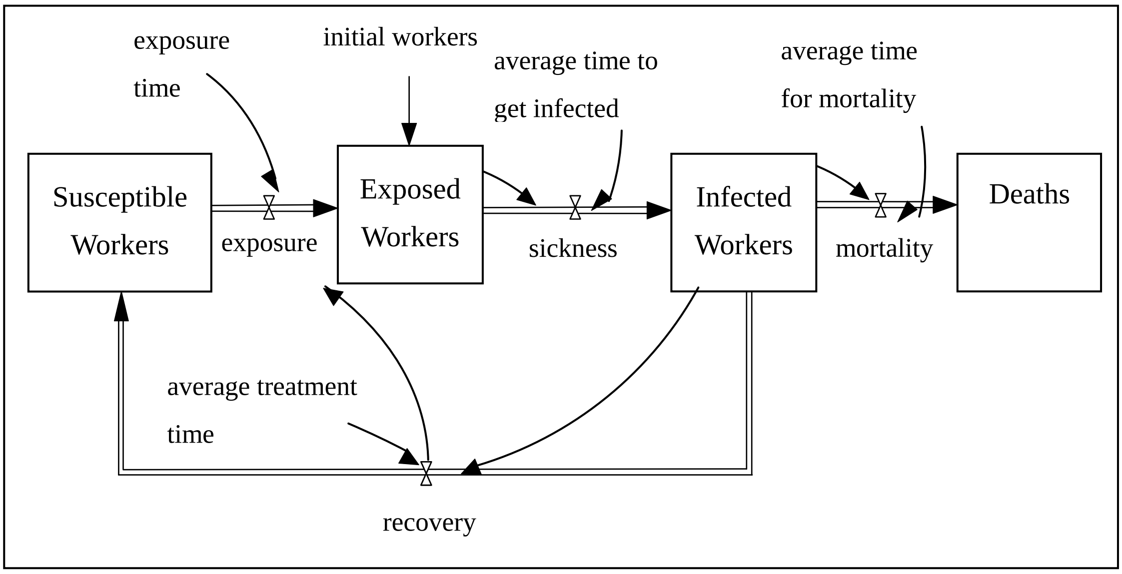

Figure 4. Exposed Workers System Dynamics Model

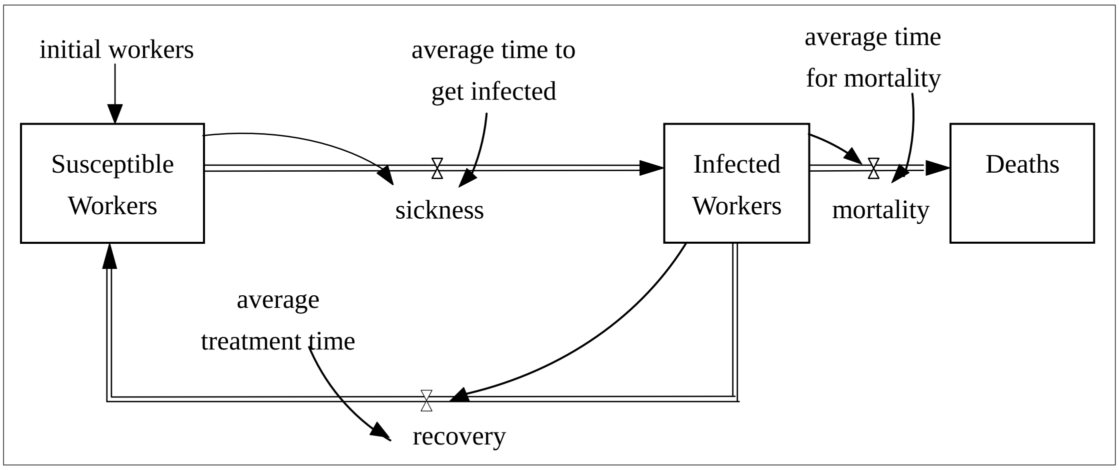

Figure 5. Non-Exposed Workers System Dynamics Model

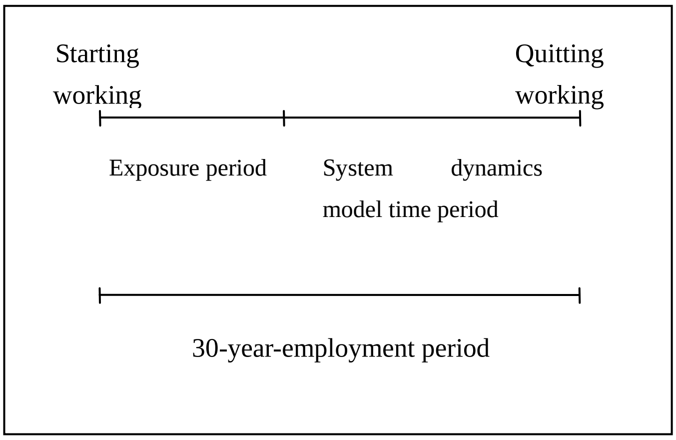

Figure 6. Time Frame for the Employees Health Models

4.1 Model Parameters and Data Sources

Since there are not a significant number of health effect investigations specifically related to healthcare wastes' treatment and disposal, municipal waste was used as a surrogate for healthcare waste. The required data for the models were gathered from both epidemiological studies providing relative risks (RR) and exposure time for a number of diseases (Section 2 Literature Review); and Turkish Statistics Databases which provided frequency of each specific disease in the non-exposed population. Table 2 presents the relative risk values of certain diseases in the measured exposure period given by these studies.

The parameter called "average time to get infected" in Exposed Workers System Dynamics Model was derived from the frequency of each specific disease in non-exposed population and the relative risk of each disease by following these steps;

(1) The frequency of each specific disease in non-exposed population ($f_{non\text{-}exposed}$) was gathered from nationwide records of annual hospital admissions in Turkish Health Statistics Database (Turkish Statistical Institution 2007)

(2) The frequency of each specific disease in exposed population ($f_{exposed}$) was calculated from the equation (Eq.4) (RRs are as provided in Table 2)

$$RR = f_{exposed} / f_{non\text{-}exposed}$$

Eq.4: Relative Risk (Giusti 2009)

(3) The exposed frequencies were converted into time constants corresponding to the average time it takes for someone to be infected. This facilitates computing the output rate (namely "sickness") by dividing the stock (namely "Exposed Workers" by the rate (namely "average time to get infected") and not multiplying it by a frequency.

$$\text{Average time to get infected} = 1/\ f_{exposed}$$

Eq.5: Conversion of Frequency to Time Constant in Exposed Workers System Dynamics Model

In converting frequencies to a time constant in Non-Exposed Workers System Dynamics Model, the parameter called "average time to get infected" was derived from the non-exposed frequency of each disease;

$$\text{Average time to get infected} = 1/\ f_{non\text{-}exposed}$$

Eq.6: Conversion of Frequency to Time Constant in Non-Exposed Workers System Dynamics Model

(4) The parameter called "Average time for mortality" was derived from a mortality rate of each specific disease by using the same correlation as above. Whereas the exposure of hazardous emissions was reported to increase mortality (Table 2 incineration mortality), "average time for mortality" of each disease was derived from the exposed mortality rates which is equal to multiplication of non-exposed mortality rate (Turkish Statistical

Institution 2007) and $RR_{mortality}$ (Table 2).

Table 3, 4 and 5 present the preparation of data to input to the models by following the steps above. Mathematical formulations and units for the parameters are presented in Appendix (Section 10).

Table 2. Data Sources for the Employees Health System Dynamics Models

Landfill (Morbidity)			**Incineration (Morbidity)**		
	RR	exposure time (years)		RR	exposure time (years)
Respiratory Problems [1]	2.14	1	Skin Symptoms [2]	4.85	12.6
Dermatologic Problems [1]	2.07	1	Daily Cough [2]	6.58	12.6
Neurologic Problems [1]	1.89	1	**Incineration (Mortality)**		
Gastrointestinal Problems [1]	1.26	1	Oesophageal Cancer [3]	2.84	18.7
Hearing Problems [1]	1.73	1	Stomach Cancer [3]	1.27	18.7
Itching Eyes [1]	1.54	1	Rectal Cancer [3]	2.52	18.7
Sorethroat [1]	2.26	1	Lung Cancer [3]	3.55	18.7
-	-	-	Bladder Cancer [3]	1.98	18.7
-	-	-	Malignant Cerebral Tumors [3]	2.77	18.7
-	-	-	Hematopoietic Cancer [3]	1.35	18.7
-	-	-	Nervous Disease [3]	1.33	18.7
-	-	-	Ischemic Heart Disease[3]	1.38	18.7
-	-	-	Respiratory Problems [3]	1.62	18.7
-	-	-	Liver Cirrhosis [3]	4.54	18.7
-	-	-	Gastric Cancer [4]	2.79	10

[1] Gelberg (1997) [2] Hours *et al.* (2003)
[3] Gustavsson (1989) [4] Rapiti *et al.* (1997)

Table 3. Data Preparation for Landfill Workers

MORBIDITY	1st STEP		2nd STEP	3rd STEP		4th STEP	
Disease	$f_{non\text{-}exposed}$	RR	$f_{exposed}$	average time to get infected (Non-Exposed Workers System Dynamics Model)	average time to get infected (Exposed Workers System Dynamics Model)	mortality rate	average time for mortality
	dimensionless	dimensionless	dimensionless	1/ dimensionless	1/ dimensionless	dimensionless	1/dimensionless
Respiratory Problems	7.68×10^{-3}	2.14	16.44×10^{-3}	130	61	1.50×10^{-2}	67
Dermatologic Problems	1.63×10^{-3}	2.07	3.37×10^{-3}	613	297	0.10×10^{-2}	1 000
Neurologic Problems	2.12×10^{-3}	1.89	4.01×10^{-3}	472	249	1.30×10^{-2}	77
Gastrointestinal Problems	5.52×10^{-3}	1.26	6.96×10^{-3}	181	144	0.90×10^{-2}	111
Hearing Problems	0.43×10^{-3}	1.73	0.74×10^{-3}	2 326	1 351	0.02×10^{-2}	5 000
Itching Eyes	0.64×10^{-3}	1.54	0.99×10^{-3}	1 563	1 010	0.00×10^{-2}	-
Sorethroat	0.02×10^{-3}	2.26	0.05×10^{-3}	50 000	20 000	0.10×10^{-2}	1 000

Average treatment time was assumed 1 year and
Number of workers in a landfill site (initial workers) was assumed to be 10
Time period of model is 29 years (by taking into account a 1 year exposure in 30-year-employment time)

Table 4. Data Preparation for Incineration Workers' Morbidity

MORBIDITY	1st STEP		2nd STEP	3rd STEP		4th STEP	
Disease	$f_{non\text{-}exposed}$	RR	$f_{exposed}$	average time to get infected (Non-Exposed Workers System Dynamics Model)	average time to get infected (Exposed Workers System Dynamics Model)	mortality rate	average time for mortality
	dmnless	dmnless	dmnless	1/dmnless	1/dmnless	dmnless	1/dmnless
Daily Cough	1.24×10^{-5}	6.58	8.16×10^{-5}	80 645	12 255	3.36×10^{-3}	298
Skin symptoms	1.63×10^{-3}	4.85	7.91×10^{-3}	613	126	1.11×10^{-3}	901

dmnless: dimensionless
Average treatment time was assumed 3months (0.25 year)
Time period of model is 17.4 years (by taking into account a 12.6 year exposure in 30-year-employment time)

Table 5. Data Preparation for Incineration Workers' Mortality

MORTALITY	1st STEP	3rd STEP	4th STEP				
Disease	$f_{non\text{-}exposed}$	average time to get infected	non-exposed mortality rate	average time for mortality (Non-Exposed Workers System Dynamics Model)	$RR_{mortality}$	exposed mortality rate	average time for mortality (Exposed Workers System Dynamics Model)
	dmnless	dmnless	dmnless	1/dmnless	dmnless	dmnless	1/dmnless
Oesophageal Cancer	$5.38x10^{-5}$	18 587	$48x10^{-3}$	20.8	2.84	$136.0x10^{-3}$	7.35
Gastric (stomach) Cancer	$9.92x10^{-5}$	10 081	$50x10^{-3}$	20.0	1.27	$63.5x10^{-3}$	15.75
Rectal Cancer	$7.51x10^{-5}$	13 316	$30x10^{-3}$	33.3	2.52	$75.6x10^{-3}$	13.23
Lung Cancer	$30.13x10^{-5}$	3 319	$60x10^{-3}$	16.7	3.55	$213.0x10^{-3}$	4.70
Bladder Cancer	$9.59x10^{-5}$	10 428	$30x10^{-3}$	33.3	1.98	$59.4x10^{-3}$	16.84
Hematopoietic Cancer	$23.00x10^{-5}$	4 348	$42x10^{-3}$	23.8	1.35	$56.7x10^{-3}$	17.64
Nervous Diseases	$2.15x10^{-3}$	465	$13x10^{-3}$	77.6	1.33	$17.1x10^{-3}$	58.48
Ischemic Heart Disease	$2.90x10^{-3}$	345	$36x10^{-3}$	27.8	1.38	$49.7x10^{-3}$	20.00
Respiratory Problems	$8.00x10^{-3}$	125	$15x10^{-3}$	66.7	1.62	$24.3x10^{-3}$	41.15
Malignant Tumours	$5.52x10^{-3}$	181	$6x10^{-3}$	117.4	2.77	$16.6x10^{-3}$	60.24
Liver Cirrhosis	$2.66x10^{-4}$	3 759	$58x10^{-3}$	17.2	4.54	$263.3x10^{-3}$	3.80
Gastric Cancer *	$9.92x10^{-5}$	10 081	$50x10^{-3}$	20.0	2.79	$139.5x10^{-3}$	7.17

dmnless: dimensionless

Average treatment time was assumed 5years; Time period of model is 11.3 years (by taking into account a 18.7 year exposure in 30-year-employment)

* 10 year of exposure was taken into account as reported by Rapiti *et al.* (1997)

5. Results and Discussion

Simulation runs were carried out for each specific disease to predict health impacts on employees working at landfill sites and incineration plants separately (Table 6, Table 7 and Table 8) by assuming that;

(1) There was no immunity so that after the recovery period is completed, recovered workers enter susceptible workers stock.

(2) Employees' population is closed; once a worker is recruited, he keeps working in the same workplace for 30 years without changing his job or work environment.

$$S(t) + I(t) = N$$

Eq.7: Boundary for Population

Where S (t) and I (t) are the numbers of susceptible and infected individuals (including deaths after infection) at time t, and N is the constant population size

(3) Each reported case is a non-transmissible disease; hence it does not spread over other members of the society.

Table 6. Additional Cases for Landfill Workers

	Results of Exposed Workers System Dynamics Model		Results of Non-Exposed Workers System Dynamics Model		Additional Cases (30 year)	
Disease	Number of Recoveries	Number of Deaths	Number of Recoveries	Number of Deaths	Number of Recoveries	Number of Deaths
Respiratory Problems	4.48	0.0607	2.24	0.0303	2.24	0.0304
Dermatologic Problems	0.84	0.0009	0.45	0.0004	0.39	0.0005
Neurologic Problems	1.12	0.0133	0.56	0.0073	0.56	0.0060
Gastrointestinal Problems	1.96	0.0159	1.40	0.0133	0.56	0.0026
Hearing Problems	0.20	0.0000	0.11	0.0000	0.09	0.0000
Itching Eyes	0.28	0.0000	0.17	0.0000	0.11	0.0000
Sorethroat	0.01	0.0000	0.01	0.0000	0.00	0.0000
TOTAL	8.89	0.0908	4.94	0.0513	3.95	0.0395
Figures in the table are out of 10 people as the number of workers in a landfill site (initial workers) was assumed to be 10 (Samat 2009)						

Table 7. Additional Cases for Incineration Workers' Morbidity

	Results of Exposed Workers System Dynamics Model		Results of Non-Exposed Workers System Dynamics Model		Additional Cases (30 year)	
Diseases	Number of Recoveries	Number of Deaths	Number of Recoveries	Number of Deaths	Number of Recoveries	Number of Deaths
Daily Cough	0.02	0.0001	0.00	0.0000	0.02	0.0001
Skin symptoms	1.60	0.0017	0.32	0.0004	1.28	0.0013
TOTAL	1.62	0.0018	0.32	0.0004	1.30	0.0014
Figures in the table are out of 14 as the number of workers in an incinerator (initial workers) was assumed to be 14.						

Table 8. Additional Cases for Incineration Workers' Mortality

	Results of Exposed Workers System Dynamics Model	Results of Non-Exposed Workers System Dynamics Model	Additional Cases (30 year)
	Number of Deaths	Number of Deaths	Number of Deaths
Oesophageal Cancer	0.0022	0.0009	0.0013
Gastric (stomach) Cancer *	0.0021	0.0017	0.0004
Rectal Cancer	0.0019	0.0008	0.0011
Lung Cancer	0.0165	0.0062	0.0103
Bladder Cancer	0.0019	0.0010	0.0009
Hematopoietic Cancer	0.0045	0.0034	0.0011
Nervous Diseases	0.0136	0.0104	0.0032
Ischemic Heart Disease	0.0501	0.0372	0.0129
Respiratory Problems	0.0697	0.0442	0.0255
Malignant Tumours	0.0337	0.0177	0.0160
Liver Cirrhosis	0.0166	0.0053	0.0113
Gastric Cancer*	0.0092	0.0042	0.0050
TOTAL	0.2199	0.1313	0.0886

Figures in the table are out of 14 as the number of workers in one incinerator (initial workers) was assumed to be 14.

*When the set of data documented by Rapiti *et al.* 1997 was taken into account, more additional cases for gastric cancer mortality were gathered (0.0050>0.0004), hence 0.0050 should be taken into account in the worst case scenario.

Table 9 presents total additional cases (mortality and morbidity) based on each reported case sourced in Table 2. Based on the inputted data to the models, a 40.0% (3.95 more cases out of 10 landfill employees) increase and a 9.3% (1.3 more cases out of 14 incinerator employees) increase in hospital admissions (morbidity) is expected to occur over the 30-year employment time. Likewise mortality rate is expected to go up by 0.4% in landfill employees and 0.6% in incinerator employees over the same period of employment. It is stated by Defra (2004a) that in the UK, taking into account the amount of waste managed by each process at present, emissions to air from waste management are estimated to result in approximately five hospital admissions for respiratory disease per year, and one death brought forward due to air emission per year in the UK as a whole.

Table 9. Total Additional Cases in the 30 year Employment Period

	Incineration				Landfill			
	Exposed Workers Population	Non-Exposed Workers Population	Total Additional Cases		Exposed Workers Population	Non-Exposed Workers Population	Total Additional Cases	
			Number	(%)			Number	(%)
Morbidity	1.62 (Table 7)	0.32 (Table 7)	1.30	9.3	8.89 (Table 6)	4.94 (Table 6)	3.95	40.0
Mortality	0.0018 (Table 7) + 0.2199 (Table 8)	0.0004 (Table 7) + 0.1313 (Table 8)	0.0900	0.6	0.0908 (Table 6)	0.0513 (Table 6)	0.0395	0.4

6. Conclusion

This study contributes to the waste management decision making process by reviewing adverse health outcomes of healthcare waste incinerators and landfill sites on workers by developing a mechanism to measure additional cases due to the exposure to hazardous emissions released from waste treatment technologies. This provides the employees' health issue to be identified as a factor which could be expressed in a quantitative scale; hence the importance of this factor relative to the other criteria, such as 'treatment cost' or 'environment performance' could be assessed for the planning of an optimum waste treatment system within the scope of decision making (for instance, multi-criteria decision analysis [MCDA]), which is the further step of this PhD project.

The greatest challenge emphasised in the current literature is the "confounding factors" which might not adequately be controlled in many studies such as ethnicity, gender, socio-economic or deprivation status, age, smoking/alcohol habits, medicinal drug use, occupational history, hazards from other sources, population mobility, long latency period of some diseases, the pre-existing health of the people being studied, the wealth or poverty of the people, the availability of health or social care services and other present or historical sources of pollution.

This paper suggests that further collaborative epidemiological studies using a more rigorous approach along with an appropriate methodology which takes account of possible confounding factors are required. The uncertainties surrounding the resultant outcomes of the developed models should be considered carefully when health effects are to be estimated and simulations should be repeated with updated data. It is anticipated that this will benefit in improving a way of shaping public perspective through waste treatment facilities which underlies social values in waste management decision making.

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References

Anand, S., Vrat, P., & Dahiya, R. P. (2006). Application of a system dynamics approach for assessment and mitigation of CO2 emissions from the cement industry. *Journal of Environmental Management, 79*(4), 383-398. http://dx.doi.org/10.1016/j.jenvman.2005.08.007

Burke, S. D. A., & Sawchuk, L. A. (2003). Tuberculosis mortality and recent childbirth: a retrospective case-control study of Gibraltarian women, 1874–1884. *Social Science & Medicine, 56*(3), 477-490. http://dx.doi.org/10.1016/S0277-9536(02)00048-5

Cao, J., Yang, C., Li, J., Chen, R., Chen, B., Gu, D., & Kan, H. (2011). Association between long-term exposure to outdoor air pollution and mortality in China: A cohort study. *Journal of Hazardous Materials, 186*(2-3), 1594-1600. http://dx.doi.org/10.1016/j.jhazmat.2010.12.036

Chaerul, M., Tanaka, M., & Shekdar, A. V. (2008). A system dynamics approach for hospital waste management. *Waste Management 28*(2), 442-449. http://dx.doi.org/10.1016/j.wasman.2007.01.007

Ciplak, N., & Barton, J.R. (2012). A System Dynamics Approach for Healthcare Waste Management, A Case Study in Istanbul Metropolitan City, Turkey. *Waste Management & Research, 30*(6), 576–586. http://dx.doi.org/10.1177/0734242X12443405

Defra (2004a). Department for Environment, Food and Rural Affairs. Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes Extended Summary. London, Defra commissioned Enviros Consulting Ltd and Birmingham University. Accessed from: http://archive.defra.gov.uk/environment/waste/statistics/documents/healthsummary (accessed December 2009).

Defra (2004b). Department for Environment, Food and Rural Affairs. Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes. Written by Enviros Consulting Ltd and University of Birmingham with Risk and Policy Analysts Ltd, Open University and Maggie Thurgood. London. Accessed from: http://archive.defra.gov.uk (accessed December 2009).

European Union (1999). Council Directive on Landfill 1999/31/EC. Official Journal of the European Union. Office for Official Publications of the European Communities. Luxembourg.

European Union (2000). EU Waste Catalogue 2000/532/EC. Official Journal of the European

Union. Office for Official Publications of the European Communities, Brussels.

Evenden, D., Harper, P. R., Brailsford, S. C., & Harindra, V. (2005). System dynamics modelling of Chlamydia infection for screening intervention planning and cost-benefit estimation. *IMA Journal of Management Mathematics 16*(Copyright 2005, IEE), 265-279. http://dx.doi.org/10.1093/imaman/dpi022

Gelberg, K. H. (1997). Health study of New York City Department of Sanitation landfill employees. *Journal of Occupational and Environmental Medicine*, *39*(11), 1103-1110. http://dx.doi.org/10.1097/00043764-199711000-00011

Geldart, S., Smith, C. A., Shannon, H. S., & Lohfeld, L. (2010). Organizational practices and workplace health and safety: A cross-sectional study in manufacturing companies. *Safety Science 48*(5), 562-569. http://dx.doi.org/10.1016/j.ssci.2010.01.004

Giusti, L. (2009). A review of waste management practices and their impact on human health. Waste Management 29(Compendex), 2227-2239. http://dx.doi.org/10.1016/j.wasman.2009.03.028

Gustavsson, P. (1989). Mortality among Workers at a Municipal Waste Incinerator American *Journal of Industrial Medicine 15*(3), 245-253. http://dx.doi.org/10.1002/ajim.4700150302

Hester, R. E., & Harrison, R. M. (2002). Environmental and Health Impact of Solid Waste Management Activities, Royal Society of Chemistry. Accessed from: http://www.knovel.com/web/portal (accessed July 2009)

Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P., & van den Brandt, P. A. (2002). "Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study." *The Lancet 360*(9341), 1203-1209. http://dx.doi.org/10.1016/S0140-6736(02)11280-3

Hours, M., Anzivino-Viricel, L., Maitre, A., Perdrix, A., Perrodin, Y., Charbotel, B., & Bergeret, A. (2003). Morbidity among municipal waste incinerator workers: a cross-sectional study. *International Archives of Occupational and Environmental Health 76*(6), 467-472. http://dx.doi.org/10.1007/s00420-003-0430-0

Jian Li, H., Hill, M. J., & Li Yin, S. (2008). Managing construction waste on-site through system dynamics modelling: the case of Hong Kong. *Engineering, Construction and Architectural Management 15*(Copyright 2008, The Institution of Engineering and Technology). http://dx.doi.org/ 10.1108/09699980810852646

Kollikkathara, N., Feng, H., & Yu, D. (2010). A system dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues. *Waste Management 30*(11), 2194-2203. http://dx.doi.org/10.1016/j.wasman.2010.05.012

McGregor, M. (2010). A system dynamics approach to jurisdictional conflict between a major and a minor healthcare profession. *Systems Research and Behavioral Science 27*(Copyright 2011, The Institution of Engineering and Technology), 639-652. http://dx.doi.org/10.1002/sres.1034

Mino, Y., Shigemi, J., Otsu, T., Ohta, A., Tsuda, T., Yasuda, N., Babazono, A., & Yamamoto, E. (2001). Smoking and Mental Health: Cross-Sectional and Cohort Studies in an Occupational Setting in Japan. *Preventive Medicine 32*(4), 371-375. http://dx.doi.org/10.1006/pmed.2000.0803

Mothibi, J., & Prakash, J. (2006). System dynamics modelling for the management of HIV/AIDS in Botswana: An evolution process. 6th IASTED International Conference on Modelling, Simulation, and Optimizatiom, MSO 2006, 11-13 September, Acta Press, Gaborone, Botswana.

Mudge, A. M., Ross, L. J., Young, A. M., Isenring, E. A., & Banks, M. D. (2011). Helping understand nutritional gaps in the elderly (HUNGER): A prospective study of patient factors associated with inadequate nutritional intake in older medical inpatients. *Clinical Nutrition 30*(3), 320-325. http://dx.doi.org/10.1016/j.clnu.2010.12.007

Peabody, J. W., Nordyke, R. J., Tozija, F., Luck, J., Muñoz, J. A., Sunderland, A., DeSalvo, K., Ponce, N., & McCulloch, C. (2006). Quality of care and its impact on population health: A cross-sectional study from Macedonia. *Social Science & Medicine 62*(9), 2216-2224. http://dx.doi.org/10.1016/j.socscimed.2005.10.030

Porta, D., Milani, S., Lazzarino, A. I., Perucci, C. A., & Forastiere, F. (2009). Systematic review of epidemiological studies on health effects associated with management of solid waste. *Environmental Health 8*, 60. http://dx.doi.org/10.1186/1476-069X-8-60

Rapiti, E., Sperati, A., Fano, V., DellOrco, V., & Forastiere, F. (1997). Mortality among workers at municipal waste incinerators in Rome: A retrospective cohort study. *American Journal of Industrial Medicine 31*(5), 659-661. http://dx.doi.org/10.1002/(SICI)1097-0274(199705)31:5<659::AID-AJIM23>3.3.CO;2-3

Rushton, L. (2003). Health hazards and waste management. *British Medical Bulletin 68*(1), 183-197. http://dx.doi.org/10.1093/bmb/ldg034

Samat, H. (2009). Personal Communication. Mr Samat is a technical supervisor of Kemerburgaz Incinerator for Istac Inc, Istanbul, Turkey.

Scheeres, K., Wensing, M., Severens, H., Adang, E., & Bleijenberg, G. (2008). Determinants of health care use in chronic fatigue syndrome patients: A cross-sectional study. *Journal of Psychosomatic Research 65*(1), 39-46. http://dx.doi.org/10.1016/j.jpsychores.2008.03.015

Szarka, N., Kakucs, O., Wolfbauer, J., & Bezama, A. (2008). Atmospheric emissions modelling of energetic biomass alternatives using system dynamics approach. *Atmospheric Environment 42*(Compendex), 403-414. http://dx.doi.org/10.1016/j.atmosenv.2007.09.051

Taylor, K., & Dangerfield, B. (2005). Modelling the feedback effects of reconfiguring health services. *Journal of the Operational Research Society 56*(Copyright 2005, IEE), 659-675. http://dx.doi.org/10.1057/palgrave.jors.2601862

Tekle, F. B., Tan, F. E. S., & Berger, M. P. F. (2011). Too many cohorts and repeated measurements are a waste of resources. *Journal of Clinical Epidemiology 64*(12), 1383-1390. http://dx.doi.org/10.1016/j.jclinepi.2010.11.023

Turkish Statistical Institution (2007). Health Statistics. Accessed from, http://www.tuik.gov.tr (accessed January 2009). UK DoH (2011). Department of Health. Safe Management of Healthcare Waste Version 1.0. London.

Unuvar, E., Ahmadov, H., Kızıler, A. R., Aydemir, B., Toprak, S., Ulker, V., & Ark, C. (2007). Mercury levels in cord blood and meconium of healthy newborns and venous blood of their mothers: Clinical, prospective cohort study. *Science of The Total Environment 374*(1), 60-70. http://dx.doi.org/10.1016/j.scitotenv.2006.11.043

Wolstenholme, E. (2005). The Potential of System Dynamics. Leading Edge, Issue 10. NHS Confederation, London, UK. Accessed from: http://www.symmetricsd.co.uk (accessed May 2009).

Appendix: Formulation of the Employees Health System Dynamics Models

Table A1: Exposed Workers Health System Dynamics Model

Type of Parameter	Name	Unit	Equation	Value
Stock	Susceptible Workers	people	INTEG(recovery-exposure,0)	-
Stock	Exposed Workers	people	INTEG(exposure-sickness, initial workers)	-
Constant	initial workers	people	-	*
Stock	Infected Workers	people	INTEG(sickness-mortality-recovery,0)	-
Stock	Deaths	people	INTEG(mortality,0)	-
Constant	exposure time	year	-	**
Flow	exposure	people/year	DELAY FIXED*** (recovery, exposure time , 0)	-
Constant	average time to get infected	year	-	**
Flow	sickness	people/year	Exposed Workers/average time to get infected	-
Constant	average time for mortality	year	-	**
Flow	mortality	people/year	Infected Workers/average time for mortality	-
Flow	recovery	people/year	Infected Workers/average treatment time	-
Constant	average treatment time	year	-	**

*For landfill and incineration initial workers were assumed 10 and 14 people respectively
** Section 4.1: Model Parameters and Data Sources
***DELAY FIXED (X, T, I) delays the input X for a fixed time T starting with I

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Table A2: Non-Exposed Workers Health System Dynamics Model

Type of Parameter	Name	Unit	Equation	Value
Stock	Susceptible Workers	people	INTEG(recovery-exposure,0)	-
Constant	initial workers	people	-	*
Stock	Infected Workers	people	INTEG(sickness-mortality-recovery,0)	-
Stock	Deaths	people	INTEG(mortality,0)	-
Constant	average time to get infected	year	-	**
Flow	sickness	people/year	Susceptible Workers/average time to get infected	-
Constant	average time for mortality	year	-	**
Flow	mortality	people/year	Infected Workers/average time for mortality	-
Flow	recovery	people/year	Infected Workers/average treatment time	-
Constant	average treatment time	year	-	**

*For landfill and incineration initial workers were assumed 10 and 14 people respectively
** Section 4.1: Model Parameters and Data Sources