# PEST STATUS, SUSTAINABLE PEST MANAGEMENT AND DEVELOPMENT OF AN ONLINE PEST REPORTING SYSTEM FOR HEALTHCARE FACILITIES IN SINGAPORE

**by**

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# STATUS PEROSAK, PENGURUSAN PEROSAK LESTARI, DAN PEMBANGUNAN SISTEM LAPORAN MAKLUMAT ATAS TALIAN UNTUK PUSAT KEMUDAHAN PENJAGAAN KESIHATAN DI SINGAPURA

## ABSTRAK

Tesis ini merangkumi status perosak, pengurusan perosak lestari, dan pembangunan sistem laporan maklumat atas talian untuk pusat kemudahan penjagaan kesihatan di Singapura. Lebih daripada separuh (52.5%) jumlah responden (200 orang) melaporkan bahawa semut adalah perosak yang paling kerap dijumpai di pusat kemudahan penjagaan kesihatan. Hanya 10% responden berpendapat bahawa penghapusan perosak tanpa menggunakan racun serangga adalah penting. Kurang daripada separuh daripada jumlah responden memahami kepentingan kebersihan dalam program pengurusan perosak. Sejumlah 87% responden mengetahui Pengurusan Perosak Bersepadu (IPM). Data mengenai perosak yang dikumpulkan antara tahun 2008 - 2010 menunjukkan bahawa semut, tikus, lalat, nyamuk dan lipas adalah perosak-perosak yang paling biasa ditemui di pusat kemudahan penjagaan kesihatan. Daripada lima perosak tersebut, semut merupakan perosak yang paling banyak menerima permintaan perkhidmatan. Dengan pemeriksaan yang teliti, penangkapan intensif, penutupan jurang dan pemantauan secara berterusan, tikus-tikus rumah di dalam lima blok perubatan di Hospital Besar Singapura telah dihapuskan dalam jangka 3 bulan. Sebahagian besar daripada tikus-tikus rumah ini ditangkap di lokasi-lokasi yang ada makanan (78 tikus rumah) berbanding dengan lokasi-lokasi tanpa makanan (14 tikus rumah) semasa tempoh penangkapan intensif. Selepas kesemua tikus telah dihapuskan pada Jun 2007, pemantauan dengan perangkap melekat tikus diteruskan sehingga Disember 2009, di mana tiada lagi tikus rumah yang ditangkap di dalam empat blok perubatan. Sebanyak 18 spesies semut perosak telah dijumpai and dikumpulkan. Daripada jumlah ini, spesies yang paling biasa dijumpai adalah *Pheidole parva* Mayr (25.9%), *Pheidole megacephala* (Fabricius) (25.2 %), *Paratrechina longicornis* (Latreille) (14.1%), *Monomorium pharaonis* (Linnaeus) (9.6%) dan *Tapinoma indicum* (Forel) (8.1%). Kebanyakan semut itu dikumpulkan di dalam premis and persekitaran premis. Kedua-dua umpan thiamethoxam dan indoxacarb mencapai pengurangan lebih daripada 90% untuk *P. longicornis* pada hari ketiga selepas rawatan. Bagi *T. indicum*, pengurangan lebih daripada 90% telah dicapai pada hari ketiga selepas rawatan dengan thiamethoxam dan minggu ke-empat selepas rawatan dengan indoxacarb. Dengan umpan hydramethylnon, pengurangan kedua-dua *P. megacephala* dan *P. parva* adalah lebih daripada 95% dicapai pada hari ketiga selepas rawatan. Dengan pest-online, peningkatan secara signifikan dalam pelaporan tentang isu-isu struktur, pengemasan dan perosak telah dicapai ($P < 0.05$). Pest-online membolehkan automasi proses pelaporan, penigkatan keberkesanan dalam aliran kerja, analisis data, produktiviti, kualiti perkhidmatan, menjimatkan kos yang perlu untuk penyimpanan laporan dan kebolehcapaian data dengan baik. Aplikasi mudah alih pest-online boleh digunakan sebagai satu sistem laporan yang berkesan untuk ahli profesional pengurusan perosak.

**PEST STATUS, SUSTAINABLE PEST MANAGEMENT AND DEVELOPMENT OF AN ONLINE PEST REPORTING SYSTEM FOR HEALTHCARE FACILITIES IN SINGAPORE**

## ABSTRACT

In this thesis, the pest status in healthcare facilities (HFs) in Singapore, along with the sustainable management for pest ants and rodents, were studied. Also, an online reporting system (pest-online) was developed and tested as the reporting system for HFs in Singapore. More than half (52.5%) of the 200 healthcare personnel reported ants as the most common pest they encountered in the HFs. Only 10% of the respondents felt that using non-chemical way to kill a pest is important. Less than half of the healthcare personnel understand the importance of sanitation in a pest management program.87% of the respondents had never heard of Integrated Pest Management (IPM). Pest data collected between 2008 and 2010 showed that ants, rodents, flies, mosquito and cockroach were the top five pests that commonly found in the HFs. Of the five pests, ants received the most service requests. With thorough inspection, intensive trapping, proofing and constant monitoring, the year-long roof rat infestation at the five medical blocks at Singapore General Hospital was eliminated in 3 months. Higher numbers of roof rats were caught at the food areas (78 roof rats) as compared to non-food areas (14 roof rats) during the mass trapping. After the total elimination in June 2007, monitoring with glue boards were continued to December 2009 and there was no re-infestation of roof rat inside four of the medical blocks. A total of 18 pest ant species were trapped. Of these, the most common species were *Pheidole parva* Mayr (25.9%), *Pheidole megacephala* (Fabricius) (25.2%), *Paratrechina longicornis* (Latreille) (14.1%), *Monomorium. pharaonis* (Linnaeus) (9.6%) and *Tapinoma indicum* (Forel) (8.1%). Most of the ants were found in and around premises. Both thiamethoxam and indoxacarb bait formulations achieved more than 90% reduction in *P. longicornis* counts at 3-day post-treatment. As for *T. indicum*, more than 90% reduction was achieved at 3-day and 4-week post-treatment with thiamethoxam and indoxacarb bait respectively. With hydramethylnon baits, percentage reduction for both *P. megacephala* and *P. parva* ant counts were greater than 95% at 3-day post-treatment. With pest-online, there was a significant increase in the finding of structural, housekeeping and pest issues ($P < 0.05$). Pest-online enable automation in the reporting process which improve workflow process, data analysis, productivity and service quality, it save archiving cost, and with good data accessibility. The mobile application of pest online can serve as a good reporting tool for the pest management professionals.

# CHAPTER ONE

# GENERAL INTRODUCTION

Healthcare facilities (HF) are made up of complexes buildings and service facilities with different kind of activities being carried out (Collins, 1988). There are many ways where pests can enter a HF; through ducting that enter into the building such as electrical piping and water piping (Burgess, 1984). In Singapore, pests can enter HFs through entrances, windows, ceilings, wall cracks, gaps around plumbing and pipes. It is common to find pests hitch-hiking a ride in commercial deliveries, flowers, gifts, carton boxes, bags and clothing. On ground, pest risks may come from landscape and greenery around HFs. There are various harbourages in the HFs that allow the pests to survive such as equipment with motor compartment that supply the warmth needed by the pests like refrigerators, cabinets, trolleys, etc. (Griffin, 1988).

Having pests in the HFs is undesirable because pest has the potential to spread diseases and pose unnecessary public health risk (Lee, 2002). Besides causing anxiety and distress to staff and patients (Short, 1988), pests can contaminate food, surgical instrument (Beatson, 1972), fabrics, sterile packs and dressings (Ayliffe, 1992; Wilkinson, 1988).

In the process of eliminating the pests, staff, patients with compromised health conditions, the elderly, infants and children may expose to pesticide risks. Many studies have shown that pesticide exposure have negative impact on human health (Berkowitz et al., 2003; Litovitz et al., 1990; Pezzoli and Cereda, 2013; Turner et al., 2011). Besides potentially being very hazardous to human health, many pesticides pose risk to other organisms in the environment as well (Edwards, 1983). Studies have shown that the widely used pyrethroid insecticides were commonly found in the environment (Delgado-Moreno et al., 2011; Ensminger et al., 2013; Hanzas et al., 2011; Hintzen et al., 2009; Hladik and Kuivila, 2012; Jorgenson et al., 2012; Luo et al., 2013; Philips et al., 2010).

The many negative impacts of insecticides on the environment, the side effect to human and animal as well as the increasing awareness has made Integrated Pest Management (IPM) the better alternative as a pest management system (Antignus, 2000). Through IPM, pesticides are used effectively and more efficiently for eradication of pests when threshold limit are reached (McCarty, 1995). In other part of the world, public sector buildings and hospitals are increasingly adopting IPM as part of the government legal policy (Greene and Breisch, 2002; Hancock, 2004; Nalyanya et al., 2005; Siddiqi, 2005).

There are many policies and acts that regulating and governing the healthcare system in Singapore but a written pest management policy that focus on IPM especially for healthcare facilities is clearly lacking. In addition, there is limited information on the studies of online reporting tool as the pest management reporting system for the healthcare facilities in Singapore. As such, this study aims to determine the pest status and the current pest management reporting system in the healthcare facilities. I hope the information gathered from this study can serve as a reference for future studies in promoting the implementation of IPM in healthcare facilities and in achieving a Sustainable Pest Management Program.

In view of the above, this study was carried out:

1. To study and understand the perception, attitude and knowledge of healthcare personnel towards pests and pest management.

2. To determine the common pests found (pest status) in healthcare facilities in Singapore.

3. To examine the feasibility of sustainable rodent management with intensive trapping and proofing in healthcare facilities in Singapore.

4. To study the structure-invading pest ants in healthcare facilities in Singapore and sustainability control using baits.

5. To develop “pest-online” as the online reporting tool for pest management service in healthcare facilities in Singapore and to evaluate its usability.

6. To compare pest-online with conventional paper-based reporting system.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 The Healthcare System in Singapore

Singapore has a world-class healthcare system that was ranked sixth best out of 191 countries by the World Health Organization (WHO) in 2000 (WHO, 2000). In 2014, Bloomberg ranked Singapore as the most efficient healthcare (Bloomberg, 2014).

In general, based on Ministry of Health (MOH) of Singapore, the Singapore healthcare system is categorized into primary healthcare services, hospital services, dental services, intermediate and long-term care (ILTC), residential ILTC services, and community-based ILTC services (MOH, 2014). As of 2015, 16 public hospitals (8 public hospitals, 8 national specialty centers) and 10 private hospitals constitute hospital services, and 18 polyclinics and approximately 1500 private medical clinics provide primary healthcare services. The eight public hospitals include six acute general hospitals, a women's and children's hospital, and a psychiatric hospital. The eight national specialty centers focus on cancer, cardiac, eye, skin, neuroscience, dental care, and multiple discipline healthcare services. Polyclinics and private medical clinics are located island-wide and are usually the first point of contact for patients, and they provide healthcare services such as outpatient medical treatment, immunization, health screening, medical follow-ups, and diagnostic and pharmaceutical services. In terms of capacity, public hospitals contain 185 to 2010 beds. Private hospitals usually have a smaller capacity, with 20 to 325 beds. In addition to having a 24-hour emergency department, the general hospitals provide multidisciplinary acute inpatient and specialist outpatient services.

The government is the dominant health care provider in the country, as 81% of the public hospitals' beds are heavily subsidized by the government. In 2012, the average duration of stay in the public acute care hospitals was about 5.8 days, and the average occupancy rate was about 85%. According to Singapore's Finance Minister Tharman Shanmugaratnam, Singapore's healthcare spending was over S$9 billion in 2015, and this is expected to increase to over S$13 billion in 2020 (Channel NewsAsia, 2015a).

## 2.2 The Layout of Healthcare Facilities

Healthcare facilities (HFs) such as hospitals are one of the most complicated building types, as they need to accommodate a wide range of services and support different users and stakeholders (Carr, 2011). In general, HFs in Singapore consist of a wide range of functional units that include diagnostic and treatment functions (e.g., laboratories, imaging labs, and operating theatres), inpatient-related functions (e.g., medical, surgical, pharmacy, and wards), outpatient-related functions (e.g., emergency and clinics), administrative functions (e.g., reception, registration, and record keeping), service functions (e.g., food, housekeeping, and supplies), and research and teaching functions. All functions in HFs are interrelated, which means that the configuration of HFs is complex.

Inpatient wards in Singapore have different configurations, such as nine bed rooms, two bed rooms, and single rooms with or without air conditioning or an attached bathroom and washroom. In wards without air conditioning, windows are usually opened to provide ventilation. Hospitality functions in HFs include amenities such as convenience stores, food and beverage shops, food courts, gift and flower shops, payment kiosks, and ATMs. In addition, HFs with inpatient wards have a central kitchen that provides meals for patients.

HFs also contain pantries where healthcare personnel can take a break or have a meal. Lockers are provided for healthcare personnel to keep their personal belongings. Sometimes food is kept inside the lockers as well. Washrooms are present at almost every level inside HFs for patients, the public, and healthcare personnel to use.

The loading and unloading dock is one of the busiest areas of a HF. These docks facilitate most of the materials handling for the HFs, as goods and materials are checked at this locale before being brought into the HF. Healthcare wastes are temporarily stored at designated storage locations inside a HF. These storage locations usually consist of a separate area or room of a size appropriate to manage the quantities of waste produced and the frequency of collection. Waste collection is usually arranged on a daily (or more frequent) basis, at which time wastes are transported to a designated central storage site. Dedicated routes for waste transportation avoid the patient care areas.

HFs require a complex mechanical, electrical, and telecommunications system. The cables and wiring for these systems are linked from one level to another through risers that run across the ceiling at each level. Some of the risers at each level have openings at the ceiling and floor to allow passage of cables. Parking facilities differ among HFs. Smaller HFs such as polyclinics usually have parking lots located just outside the buildings. Larger HFs such as hospitals have multilevel parking lots within the HFs located either above ground or underground (basement).

Most HFs have heavy traffic characterized by constant movement of people and materials. Visitors, patients, HF personnel, contractors, and food, linens, and other materials move through HFs constantly. The numerous entrances and exits in HFs are either fitted with automated sliding glass doors or open entrances. Passenger lifts at each level serve the public and the HF personnel. Dedicated service lifts are used for deliveries of food and goods as well as for building maintenance services.

## 2.3 Pest Intrusion into Healthcare Facilities

HFs are made up of complexes of buildings and service facilities at which different kinds of activities are conducted (Collins, 1988). Pests can enter a HF through ducting that enters the building, such as electrical and water piping (Burgess, 1984), or they can enter through open windows and entrances. Drainage pipes provides a good access path for pests as well. Pests also can disperse through all sorts of activities that take place at HFs, such as materials movement within a HF or between HFs. Pest survival is assured when various harborage sites readily exist within a HF. For example, equipment such as refrigerators, cabinets, and trolleys that supply the warmth needed by the pests are ideal sites for pests (Griffin, 1988), and HFs located near residential areas and those with ample food sources such as packages of medicines and other foods ensure the survival of ants (Lima et al., 2013).

In Singapore, it is not uncommon for pests to cross-infest HFs and their surrounding areas through patients and via commercial deliveries. According to the pest management professionals (PMP) in Singapore, German cockroaches have been found inside boxes and vegetable baskets delivered to the kitchen, gnats have been found on potted plants delivered to offices, bed bugs have been found on patient’s clothing, and millipedes have been found infesting new soils being introduced into the landscape areas. It is a common understanding that the design problems in buildings and landscapes can lead to pest ingression and infestation in the buildings so pest management should be considered during the design stage (Dhang, 2014). PMPs in Singapore reported that rodents were found to enter HFs through gaps around plumbing and pipes where they enter the building, and sewer flies and other flying insects were found to enter through open concept washrooms. Pest infestations often occur in areas that provide food, shelter, or water, such as kitchens, cafeterias, loading/unloading bays, waste rooms bathrooms, storage rooms, and patient wards.

## 2.4 Pest Risks in Healthcare Facilities

Having pests in a HF is undesirable because pests have the potential to spread diseases and pose unnecessary public health risks (Lee, 2002). In addition to causing anxiety and distress to staff and patients (Short, 1988), pests can contaminate food, surgical instruments (Beatson, 1972), fabrics, and sterile packs and dressings (Wilkinson, 1988; Ayliffe, 1992).

### 2.4.1 Ants

Ants are one of the most common pests infesting buildings (Hedges, 2010), and they have been rated the most difficult pest to control (Gooch, 1999; Moreira et al., 2005). Ants are considered to be one of the most important household pests (Yap et al., 1999; Lee et al., 2002). They also can cause significant changes to the ecosystem. For example, the invasion of *Anopolepis gracilipes* (Fr. Smith) on Christmas Island caused a substantial decline in the population of the land crab *Gecarcoidea natalis* Pocock, which had a negative impact on the ecosystem (O'Dowd et al., 2003).

Ants carry pathogens that may cause diseases that pose a threat to the general public (Lee, 2002). In a study conducted in nine hospitals in United Kingdom, six genera of pathogenic bacteria (*Pseudomonas, Salmonella, Staphylooccus, Streptococcus, Klebsiella*, and *Clostridium*) were isolated from pharaoh ants (Beatson, 1972). In a study of hospitals in the state of Santa Catarina, Brazil, 20 bacteria were isolated from 85.7% of the ants collected (Lise et al., 2006).

The pharaoh ant, *Monomorium pharaonis* (Linnaeus), is a common pest in hospitals, and it is recognized as a vector for disease (Wetterer, 2010). The foraging behavior of pharaoh ants has been shown to lead to transmission of disease (Lee, 2002), and organisms that can caused plague were found on pharaoh ants that fed on infected animal carcasses (Alekseev et al., 1972). The crazy ant, *Paratrechina longicornis* (Latrielle), is another important vector of pathogens that can cause hospital-acquired infection (Fowler et al., 1993; Bueno et al., 1994). Stings from fire ants are painful and cause a burning sensation (deShazo et al., 1990; WHO, 2008), and they have led to deaths due to anaphylactic reactions (Rhoades et al., 1989; deShazo et al., 1990).

A survey conducted in Singapore in 2004 reported that important pest ant species include *Tapinoma melanocephalum* (Fabricius) (ghost ant), *Tapinoma indicum* (ghost ant), *M. pharaonis* (pharaoh ant), *P. longicornis* (crazy ant), *A. gracilipes* (yellow crazy ant), *Monomorium floricola* (Jerdon) ('semut gatal'), *Solenopsis geminate* (Fabricius) (tropical fire ant), *Oecophylla smaragdina* (Fabricius) (weaver ant), *Pheidole megacephala* (Fabricius) (big-headed ant), and *Tetramorium spp*. (pavement ant) (Lee and Tan, 2004). Most of these pest ant species such were also reported to be commonly found pest ant species in Malaysia (Na and Lee, 2001; Lee et al., 2002).

### 2.4.2 Rodents

There are about 2000 rodent species found worldwide but only a few are commensals (Meyer, 2003). They are known as commensal rodents because they are found in close association with people (Smith et al., 2015) or popularly known as "live off man's table". The three species of rodents that are considered to be serious pests in the urban environment and are distributed worldwide are the Norway rat (*Rattus norvegicus* Berkenhout), roof rat (*Rattus rattus* Linnaeus), and house mouse (*Mus musculus* Linnaeus) (WHO, 2008). According to Natinal Environment Agency (NEA) and National Parks Board (NPB) of Singapore, the common rodent species in Singapore are *R. norvegicus*, *R. rattus*, *M. musculus, Rattus exulans* (Peale) (Polynesian rat), and *Rattus tanezumi* (Temminck) (Asian house rat) (NEA, 2005; NPB, 2015).

Rodents serve as vectors or reservoirs of a variety of diseases, such as hantavirus pulmonary syndrome, hemorrhagic fever with renal syndrome, salmonellosis, leptospirosis, plague, rat-bite fever, leishmaniasis, murine typhus, and many more (Meerburg et al., 2009). They can act as intermediate infected hosts or as hosts for arthropod vectors such as fleas and ticks (Kausrud et al., 2007). Rodents are responsible for the worldwide spread of the bacterium *Rickettsia typhi* (Gray et al., 2007; Kim et al., 2007), which causes murine typhus via the rat flea vector *Xenopsylla cheopis* (Rothschild).

Hantaviruses are rodent-borne viruses that cause hantavirus pulmonary syndrome in humans. Humans can be exposed to these viruses through inhalation of virus aerosol from the excreta of infected rodents (Anyamba et al., 2006; Kausrud et al., 2007). In an outbreak of hantavirus in Southern Argentina in 1996, strong epidemiologic evidence suggested that the route of transmission was person-to-person (Rachel et al., 1997). Bubonic plague, a disease caused by *Yersinia pestis* (Lehmann and Neumann) transmitted by the rat flea, claimed many millions of lives in the past (Perry and Fetherston, 1997). Today, many fewer cases (about 1000–3000 each year worldwide) of bubonic plague are reported (Keeling and Gilligan, 2000), but the disease is still widely spread throughout the world (Stenseth et al., 2008).

Rodents can damage property and food due to their gnawing behavior, resulting in economic losses (Brown et al., 2008; Vadell et al., 2010). Rodents destroy insulation, plumbing, and other structural components of buildings and may induce fire and electrocution by damaging electrical wirings (Hall and Griggs, 1990). In China, rodent activity was found in the Shanghai metro system, leading to concern about damage to the railway lines that could cause breakdowns (Leng et al., 2015). The frequent breakdown of Singapore's rail system has been attributed to rodent activity, and the Transport Minister Khaw Boon Wan mentioned in his blog post that more "rat catchers" are needed (The Straits Times, 2015). Chairman of Public Utilities Board (PUB) Tan Gee Paw noted that rodents caused the breakdown of an entire electricity-generating refuse incineration plant in the 1980s (Channel NewsAsia, 2015b).

### 2.4.3 Cockroaches

Cockroaches have been linked to various pathogenic organisms such as poliomyelitis viruses, bacteria, fungi, protozoa, and helminths (Lee, 1997; Cotton et al., 2000). Cockroaches are thought to be carriers of various pathogenic bacteria in hospital and residential areas (Bouamamaa et al., 2010). Due to their habit of feeding on trash, inhabiting sewers, drainage areas, and other unsanitary places, and regurgitating while feeding, cockroaches pose a potential public health risk via contamination of human food and transmission of various pathogenic microorganisms (Lee et al, 2003; Graczyk et al., 2005; Pai et al., 2005). Cockroaches can transmit cysts of human protozoan parasites due to their habit of feeding on human feces (Fotedar et al., 1991; Pai et al., 2003).

A study conducted in Thailand showed that the following medically important bacteria species were isolated from *Periplaneta americana* (Linnaeus) (American cockroach) and *Blatta orientalis* (Linnaeus) collected from hospitals (Chaichanawongsaroj et al., 2004): *Enterobacter* spp., *Klebsiella* spp., *Citrobacter* spp., *Escherichia coli* (Migula), *Salmonella* spp., *Proteus* spp., and *Serratia* spp. In Malaysia, 14 species of bacterial pathogens were isolated from various species of cockroaches trapped from household areas and in a hospital (Rampal et al., 1983). More than 22 species of bacterial pathogens, viruses, fungi, and protozoans and 5 species of parasitic worms were isolated from *P. americana* collected from the field (Rust et al., 1991). Mullins and Cochran (1973) demonstrated compounds that contained either mutagens or carcinogens inside cockroach's feces.

In many parts of the world, inhalants and allergens produced by cockroaches have been associated with asthma (Platts-Mills et al., 1997; Eggleston, 2001), and there was an increase of allergy and asthma problems associated with cockroaches (Kang and Chang, 1985; Brenner et al., 1991; Lee, 1997). Studies have documented an association between exposure to cockroach allergens in early life and recurring asthmatic wheezing in children with a family history of atopy (Litonjua et al., 2001). Small numbers of cockroaches are capable of producing a significant amount of allergen; for example, an adult female *Blattella germanica* (Linnaeus) (German cockroach) can generate 25,000 to 50,000 units of allergens in their lifetime (Gore and Schal, 2005).

A survey organized by Singapore Pest Management Association (SPMA) in Singapore revealed that *P. americana* and *B. germanica* were the most commonly found species (Lee and Ng, 2009). Other predominant cockroach species found include *Supella longipalpa* (Fabricius) (Brown-banded cockroach) and *Symploce pallens* (Stephen) (Smooth cockroach) as well as *Periplaneta brunnea* Burmeister (Brown cockroach), *Periplaneta australasiae* (F.) (Australian cockroach) and *Neostylopyga rhombifolia* (Stoll) (Harlequin cockroach) which were moderately prevalent.

### 2.4.4 Flies

At least 120,000 species of flies from 108 families have been described to date (Olsen, 1998). From this, 47 species are categorized as "filth flies" due to their habit of visiting human or animal excrement, which may result in the spread of pathogens. Nearly half of the 47 species are considered to be disease-causing flies because they act as agents of myiasis or as carriers of enteropathogenic *E. coli*, *Salmonella*, *Shigella*, and other food-borne pathogens (Olsen, 1998). Besides being the natural carriers of various pathogens (Rosef and Kapperud, 1983; Szalanski et al., 2004; Banjo et al., 2005; Forster et al., 2009), different species of flies can harbor as many as 100 species of pathogens (Forster et al., 2009). Greenberg (1964) reported a direct relationship between fly density and diarrheal diseases, and in a study conducted at a hospital, Fotedar et al. (1992) found that most of the bacteria isolated from houseflies collected at a surgical ward were medically important.

The most medically important species of flies include houseflies (Muscidae), blow flies (Calliphoridae), lesser houseflies (Fanniidae), and flesh flies (Sarcophagidae) (Greenberg, 1973; Graczyk et al., 2001). Some of the common filth flies in Singapore include houseflies, blow flies (family Calliphoridae), flesh flies (family Sarcophagidae), and lesser house flies (*Fannia* spp.)

Houseflies breed and feed in unsanitary places such as on garbage, animal manure, carcasses, and sewage, which are filled with bacteria and other microorganisms that may be pathogenic (Lee et al., 2003; Graczyk et al., 2005). Due to their close association with humans, houseflies act as mechanical vectors by transferring many bacterial pathogens to humans (Rosef and Kapperud, 1983).

A small number of bacteria in housefly's defecation can multiply and potentially cause disease in humans (Kobayashi et al., 2002). Studies have shown that regurgitation spots of houseflies allowed *E. coli* to survive on spinach leaves and that fly regurgitation is a potential disease dissemination route (Talley et al., 2009; Wasala et al., 2013). Houseflies also can transmit gastrointestinal diseases such as shigellosis, salmonellosis and cholera (Greenberg, 1971; De Jesus et al., 2004), and Wanaratana et al. (2011) showed that *Musca domestica* (Linnaeus) can carry the avian influenza (AI) H5N1 virus and transmit it mechanically.

### 2.4.5 Mosquitoes

Mosquitoes are distributed worldwide except for Antarctica and some islands. In Europe and North America, mosquitoes are more important as a nuisance pest, but in many tropical and subtropical regions they are important vectors of viruses, parasitic protozoa (plasmodia), and filarial worms (WHO, 2008). In addition to being the vector of the most important human viral disease, dengue (Rigau-Perez et al., 1998), mosquitoes are vectors of the pathogens that cause encephalitis, malaria, yellow fever, chikungunya fever, filariasis, and West Nile fever (Lee et al., 2003; WHO, 2008). Rogers et al. (2006) reported that one-third of the world population is at the risk of exposure to the dengue virus. Using the global risk map for dengue and the global database of the occurrence of dengue, Rogers et al. (2014) predicted widespread dengue risk in Southeast Asia and India, Central America, and parts of coastal South America. Annually, there was an estimate of 500,000 severe dengue cases with 12,500 deaths reported worldwide (WHO, 2015).

Dengue fever and dengue hemorrhagic fever are the most common mosquito-borne viral disease mainly transmitted by *Aedes aegypti* (Linnaeus); they are also transmitted by *Aedes albopictus* (Skuse) but to a lesser degree (Gubler and Clark, 1995; WHO, 2015). The four virus serotypes of dengue are DEN-1, DEN-2, DEN-3, and DEN-4 (Halstead, 1988). Because there is no cross-immunity between the four serotypes, a person can have more than one dengue infection during his or her lifetime (Gubler, 1998; NEA, 2008). The first dengue hemorrhagic fever case was discovered in the 1950s in the Philippines and Thailand during dengue epidemics (WHO, 2015).

Zika virus (ZIKV) is another emerging mosquito-borne virus that has been reported around the world in recent years (WHO, 2016). ZIKV is a member of the Flaviviridae family, and it also is transmitted by the *Aedes* mosquito and causes symptoms similar to those of the dengue virus (Ioos et al., 2014; WHO, 2016). The virus was first discovered in 1947 in Uganda (Dick et al., 1952). Infection cases were rare until the first outbreak of Zika virus disease in 2007 on the island of Yap, Micronesia (Duffy et al., 2009; Lanciotti et al., 2007; Ioos et al., 2014).

In Singapore, the first dengue fever epidemic was reported in 1901 (Moore 1904), and the incidence of dengue increased more than 10-fold from 1987 to 2004 (MOH, 2007). There were four dengue outbreaks in Singapore over the past eight years; 2004, 2005 2007 and 2011 (Hii et al., 2012). In a study conducted to determine the seroepidemiology of dengue virus infection among adults in Singapore, the Singapore population was found to be highly susceptible to dengue epidemics (Yew et al., 2009).

According to the Environmental Health Department of the National Environment Agency of Singapore, more than 80 species of mosquito can be found in Singapore. However, most of them are rather uncommon and rarely pose any public health risk. The important mosquito species in Singapore are those capable spreading mosquito-borne viral diseases, namely *Ae. aegypti*, *Ae. albopictus*, *Culex* spp. (Linnaeus), and *Anopheles* spp. (Meigen) (NEA, 2008).

## 2.5 Pesticides Risk on Human Health in Healthcare Facilities

Human uptake of pesticides mainly occurs through the skin and eyes and by inhalation, ingestion, and dermal absorption. Some pesticides pose potential hazards to humans due to their carcinogenic effects on animals. Besides potentially being very hazardous to human health, many pesticides pose risk to other organisms in the environment as well (Edwards, 1983). Studies have shown that the widely used pyrethroid insecticides were commonly found in urban and agricultural streams in the United States which pose risk to the non-target organism (Hintzen et al., 2009; Philips et al., 2010; Delgado-Moreno et al., 2011; Hladik and Kuivila, 2012; Ensminger et al., 2013). Pesticides can enter waterways through overwatering of treated (with pesticides) plants (Hanzas et al., 2011) and through runoff from treated surfaces that are impermeable (e.g., concrete) (Jorgenson et al., 2012; Luo et al., 2013).

Humans can be exposed to insecticides indirectly, as insecticides can absorb onto surfaces such as textiles and other materials during application (Berger-Preis et al., 1997). Insecticide also may produce residues that cannot be decontaminated with regular cleaning. In a study conducted in a kindergarten, residues of insecticides used against cockroaches were still detected after several months, even after great decontamination efforts were made (Fisher et al., 1999).

Berkowitz et al. (2003) described an increase in indoor pesticide exposure in the United States from 1998 to 2001, especially in urban settings where the pesticide concentration may be high. Litovitz et al. (1990) reported about 67,000 non-fatal pesticide poisonings each year and about 27 accidental fatalities (non-suicides or homicides) per year in the United States. Studies have documented a positive correlation between residential pesticide exposure in pregnant mother and younh child, and childhood leukemia (Turner et al., 2011). Pezzoli and Cereda (2013) showed that the risk of Parkinson disease increased with exposure to pesticides, herbicides, and solvents.

## 2.6 Integrated Pest Management

Before the idea of integrated pest management (IPM) was introduced, the term "integrated control" was created by four entomologists at the University of California to describe a method to mitigate the problems associated with the indiscriminate use of insecticides which lead to problems such as pest resistance, pest recurrence, outbursts of secondary pests, and environmental pollution (Stern et al., 1959; Ehler, 2006). They defined integrated control as "applied pest control which combines and integrates biological and chemical control," and they successfully used this approach to achieve integrated control against the spotted alfalfa aphid.

IPM has different definitions and objectives within the structural pest management industry, and there is no single definition to describe IPM or a list of techniques to achieve it. According to Kogan (1998), "IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on products, society, and the environment." However, between 1959 and 2000 there were at least 67 definitions of IPM in the literature around the world (Bajwa and Kogan, 2002).

IPM was first introduced in the agroecosystem to consider economic parameters before taking action to control a pest (Stern et al., 1959). Thus, IPM for urban settings was mainly derived from the concepts of agricultural IPM (Stern et al., 1959), such as correct identification of pests, judicious use of pesticides, monitoring of pests, action thresholds, and proper documentation (Flint et al., 2003). IPM was brought into the urban environment because of the ill effects on human health caused by increased exposure to pesticides and insects (Brenner et al., 1990; Robinson, 1996).

The increasing awareness of the negative impact of pesticides on the environment and human health in the past decade has made IPM the better alternative as a pest management system as compared to the common method which mainly rely on pesticides (Antignus, 2000). Using insecticides to manage pests is not desirable because they negatively impact the environment and have side effects that affect human and animal health (Alarcon et al., 2005). Through IPM, pesticides are used effectively and more efficiently for eradication of pests when threshold limit are reached (McCarty, 1995).

In a study carried out in housing apartments at the University of Florida to evaluate the effectiveness of an IPM program in reducing the exposure of residents to pesticides and pests, the amount of insecticide used was significantly reduced by 92% per year with the IPM program (Juneau et al., 2011). The program included resident education, routine inspections, and an organized decision-making process based on pest monitoring, identification, and the use of safe and effective pest management methods. To reduce the use of insecticides, nonchemical methods such as exclusion, improving housekeeping and sanitation, and trapping can be used to manage pests (Glass et al., 1997; Juneau et al., 2011).

The continuous use of pesticides can lead to resistance in arthropods. A Michigan State University database listed 7747 cases of resistance involving 331 insecticide compounds, and from the 10,000 arthropod pests included, 553 species showed resistance to insecticides (Whalon et al., 2008). Pesticide resistance in arthropods impacts crops production, animal production, structural and urban pest management, and human health.

The IPM strategy provides the best possible multiple component approach to managing pest issues with the most effective and appropriate methods (Chant, 1964).

According to Ehler (2006), integration in IPM means the use of natural enemies and compatible methods that will not endanger natural enemies. In a 2-year study using African weaver ants (*Oecophylla longinoda* Latreille) as the natural enemy combined with fruit fly baits as the compatible measure against Beninese cashew pests on cashew trees, significantly higher harvests were achieved as compared to cashew trees without ay control measures (Anato et al., 2015).

In California, an ant IPM program in schools that involved significant reduction in pesticide sprays through prevention and the use of less hazardous treatments such as baits, soapy water sprays, sealing, and improved sanitation practices was found to be effective (Sutherland, 2012). In general, the concept of IPM stresses pest prevention using cultural management, natural enemies, etc. to limit the occurrence of pests whenever possible, with pesticides used only when it is deemed necessary (Bajwa and Kogan, 2002). With IPM, different pests can be managed at the same time using multiple methods. IPM aims to achieve long-term and sustainable pest management and to minimize the risk to human health, the environment, and non-target organisms (Flint et al., 2003).

Based on Lee and Ng (2009), an IPM program has six essential steps: 1) identify pests, 2) determine level of infestation through surveillance, 3) determine management strategies, 4) conduct source reduction, sanitation, and customer education, 5) implement treatment, and 6) conduct post-treatment monitoring and follow-up. In a study of the implementation process of an IPM program in child care centers, Kalmar et al. (2014) identified the following four stages: 1) awareness of IPM, 2) knowing the importance of IPM and how to practice it, 3) the push factor to adopting IPM, and 4) implementation of IPM.

Education is an important factor in IPM. Studies have shown that continuing education can raise awareness about pests and ensure that an urban IPM can be implemented (Byrne et al., 1984). With education, pest prevention can be effected, sanitation can be improved, and tolerance towards non-risky pests can be increased (Robinson and Zungoli, 1985; Greene and Breisch, 2002). A survey of public attitudes toward urban arthropods showed that more educated people were more likely to tolerate outdoor pests compared to less educated people (Hahn and Ascerno, 1991).

Around the world, public sector buildings are increasingly adopting IPM as part of the government legal policy (Greene and Breisch, 2002). In the United States, an act that will require school districts to implement IPM programs passed unanimously in the General Assembly of North Carolina (Nalyanya et al., 2005). IPM is fast becoming the standard for pest management in American HFs due to recommendations by various healthcare related organizations such as the Centers for Disease Control and Prevention (CDC), the US Environmental Protection Agency (EPA), Hospitals for Healthy Environment (H2E), and the American Society for Healthcare Environmental Services (ASHES) (Siddiqi, 2005). In Boston, MA, at least 10 hospitals have adopted IPM over the past 15 years, and they no longer use any rodenticides and pesticide sprays and do not conduct pesticide applications as preventive measures. In addition, the University of Rochester Medical Center in Rochester, NY has successfully cut down the cost for materials and labor by reducing the pesticide risks to patients, staff, and the public by eliminating preventive pesticide sprays, aerosol sprays, and the used of organophosphate insecticides (Hancock, 2004).

## 2.7 Ant Baiting

Unlike residual sprays that provide temporary control by killing the foragers that only formed a small percentage of the entire ant colony, ant baits provide more long-term control (Daane et al., 2008). Baiting is the best approach to controlling ants because it is more environmentally friendly than residual insecticides, the use of which may lead to contamination or insecticide exposure (Oi et al., 1994; Fischer et al., 1999; Rust et al., 2008). In addition, the used of pyrethroid insecticides can cause budding (Lee et al., 1999; Buczkowski et al., 2005), which may deteriorate the ant infestation.

Many studies have shown that baiting provides good control for ants. Hydramethylnon granular baits have been shown to provide effective control against ant species such as *Solenopsis invicta* (Buren), *P. megacephala*, *Monomorium destructor* (Jerdon), and *M. pharaonis* (Linnaeus) (Davis and Schagen, 1993; Lee, 2000; Williams et al., 2001). Chong and Lee (2009) showed that indoxacarb bait provided 100% reduction of *Anoplolepis gracilipes* (Fr. Smith) in 14 days. In another study, *S. invicta* activities in more than 90% of the mound were eliminated in 9 days with the use of indoxacarb baits (Barr, 2003). The effectiveness of thiamethoxam liquid bait was evaluated against Argentine ants (*Linepithema humile* Mayr) around homes in southern California, and the result showed a reduction of more than 80% of ants (Klotz et al., 2009). In a study conducted by Williams et al. (1999), significant reduction of an internal pharaoh ant population was achieved with external baiting treatment and without the use of any pesticides internally. Baiting treatment at the external perimeter of buildings is essential because structure-invading pest ants nest and forage outdoors as well (Oi et al., 1994).

Baits work by making use of the ants' social grooming behavior and trophallaxis (food sharing) to distribute the baits within the colony (Jordan et al., 2013). For a baiting treatment to be successful, the baits must be readily accepted by the ants, a sufficient amount of bait must be ingested, and the ants must have sufficient time to bring the active ingredients back to the nest (delayed toxicity) and disseminate it to the entire colony (Davis and Schagen, 1993; Oi et al., 1994; Klotz and Williams, 1996; Collins and Callcott, 1998; Lee, 2000; Jordan et al., 2013). Factors that affect the uptake of baits by ants are the bait base (liquid, gel, paste, or granular), the attractant, and the active ingredient used (Lee, 2002) as well as the nutritional preference of the ant colony (Lee, 2008). It was reported that *P. longicornis* and *T. indicum*, along with other ant species tested, preferred a liquid bait base followed by a gel bait base (Lee, 2008). Starvation has a positive effect on the intake of bait by ants, thus influencing the success of the baiting treatment (Mathieson et al., 2012). As such, it is essential to deprive the ants of food during a baiting program.

## 2.8 Insecticides and Their Mode of Action

In the ant baiting project in this study, the following insecticides were tested on their efficacy against structure-invading pest ants: neonicotinoid (thiamethoxam), oxadiazine (indoxacarb) and amidinohydrazone (hydramethylnon).

### 2.8.1 Neonicotinoid (thiamethoxam)

Thiamethoxam is a systemic insecticide that currently is the fastest growing class of insecticides (Muccio et al., 2006). It is a neonicotinoid and affects the nicotinic acetylcholine receptors in the insect nervous system; it is widely used to manage public health insect pests as well as insect pests of agricultural (Maienfisch et al., 2001; Li et al., 2012). Unlike nicotinoids, neonicotinoids have low toxicity to mammals, fish, and birds (Tomizawa and Casida, 2004). Neonicotinoid insecticides play an important role in IPM strategies because they are very target specific, are relatively less harmful to the environment, and are more flexible in the application methods (Jeschke et al., 2011).

### 2.8.2 Oxadiazine (indoxacarb)

Indoxacarb is an oxadiazine. It is considered to be a reduced-risk pesticide that affects insects mainly through ingestion. The development of symptoms is slow with indoxacarb, as the actual toxin can only be released through metabolism. The metabolite of indoxacarb inhibits the sodium channel function in the insect nervous system (Wing et al., 2000; Barr, 2003; Lahm et al., 2009), which leads to neurotoxicity and eventually death (Wing et al., 2000). Indoxacarb is the first oxadiazine insecticide, and it is mainly used against agricultural pests (Harder et al., 1997; Wing et al., 2000). Buczkowski et al. (2008) reported significant parallel transfer of indoxacarb in the German cockroach.

### 2.8.3 Amidinohydrazone (hydramethylnon)

Hydramethylnon is the only member of the class of amidinohydrazone insecticides (Yu, 2015). Hydramethylnon is a metabolic inhibitor that can cause substantial mortality in adult ants (Oi et al., 2000). It is used to control some species of pest ants and cockroaches (Yu, 2015). Studies have shown that Amdro®, which contains hydramethylnon, was the most commonly recommended granular bait to use