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**DESIGN OPTIMIZATION AND UP-SCALING OF FIRE FIGHTING MACHINE:  
WATER SPRAYING AND TRACK MECHANISM SYSTEM APPROACH**

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## ABSTRACT

### **DESIGN OPTIMIZATION AND UP-SCALING OF FIRE FIGHTING MACHINE: WATER SPRAYING AND TRACK MECHANISM SYSTEM APPROACH**

*(Keywords: optimization, fire fighting, water spraying, control system)*

Fire fighting is risky profession. They are not only extinguishing fires in tall buildings but also must drag heavy hoses, climb high ladders and carry people from buildings and other situations. There are many fire fighters lost their lives in the line of duty each year throughout the world. The statistics of the fire fighter fatalities are still maintain at high level every year and it may continue to increase if there is no improvement in fire fighting techniques and technology. The report describes the findings on water pressure loss analysis and track mechanism system of fire fighting mobile robot prototype.

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## 1.0 INTRODUCTION

Fire fighter need to work in a long and irregular hours and unfriendly working environment such as high temperature, dusty and low humidity, firefighters are also facing with potentially life threatening situation such as explosion, collapsed building and radioactive. The common equipment used by firefighters such as flat head axe, halligan bar, turnout jacket, fire retardant or bunker pants, boots, flashlight, helmet, face mask, and gloves do not significantly reduce risk on their lives when facing those life threatening situations.

In the USA, the traumatic death rate amongst firefighters shows that 1.9 firefighters are killed per year, per 100,000 structure fires which is the rate only slightly lower than that obtained in the early 1980s (IAFF, 2000). However, this rate was increasing to 3.0 per 100,000 structure fires across a thirty year period which is peaking in the 1990s (Kyle, 2007). There are many causes for Line of Duty Deaths (LODD) such as smoke inhalation, burns, crushing injuries and related trauma (Rosmuller and Ale, 2008). As a result of this, over the past few years, research and development on firefighting technology is extensively made around the world especially in US, Japan, and a number of European companies. There were many studies (SQFE, 2007; Sofge, 2007; Konda, 2008; HKFSD, 2008; NEVA, 2008) had emphasized on machine development to replace fire fighter to fight fire in dangerous situations and to reduce the fire fighter risk. The machines help the fire fighter using extinguishing agent such as water, foam or others without fire fighter having to set up or operate directly in danger areas.

Amano (2000) highlighted the weaknesses of existing machine design and suggest integration of all important elements in developing fire fighting machine so that a successful rescuing process can be achieved. These elements are size, weight, cost and performance. Therefore, this research was integrated required technical aspects to develop a mobile machine based on the end user requirements which is fire fighting rescue team. The paper describes the water pressure loss analysis of the developed fire fighting mobile robot.

## 2.0 CURRENT FIRE FIGHTING MOBILE ROBOT

The rapid development in technology nowadays, directly improve the tools and equipment used in fire fighting. With these advance tools and equipment, fire fighting can be more effective and efficient. Besides, it also reduces the risk to minimum level. Moreover, the damages of fire incident can be reduced. Fire fighting mobile robot is one of the solution that able to reduce the fire hazards risk on fire fighter. Different type of current available fire fighting machine will be described.

### ***LUF60:***

LUF60 (Figure 1) is a diesel powered mobile fire fighting machine is equipped with air blower and a water beam fog. The machine is able to clear the hazardous obstacles by blowing the mixture of air and water. Besides, the machine is designed to withstand the rigor operating conditions and confined spaces. The LUF60 can be used in rail

tunnels, aircraft hangers, parking garages, chemical plant, etc. There are some significant features of this machine. The monitor nozzle has a flow rate up to 800 GPM and it can blow the water beam as far as 80m. In order to enhance its mobility in high temperature condition, it is equipped with a rubber track system which is rated to 400 degrees Fahrenheit. The rubber track system enables the robot to climb the stairs. Besides, this machine is able to operate on slopes of maximum 20 degrees with the ventilation tube at a maximum 45 degree angle (NRT, 2013).



Figure 1: LUF60  
(Photo reprinted from NRT, 2013)

### ***FIREROB:***

FIREROB (Figure 2) is a remote controlled mobile robot that is used to fight fires, search and inspect fire scene. The FIREROB is protected from heat with a heat shield. It is equipped with high-pressure water mist extinguishers to control the fires. Besides, it is also equipped with thermal imaging cameras and sensors for observation and monitoring purposes in fire scenes. Two operation options for the FIREROB are available, which are with heat shield and without heat shield.



Figure 2: Service Robot FIREROB (Photo reprinted from Americancrane, 2009)

### ***FFR-1:***

FFR-1 (Figure 3) is a fire fighting robot that used to enable firefighters to carry out difficult missions. The FFR-1 is a remote controlled double-tracked robot that carry monitor and used to extinguish fire. The robot is designed to operate under hazardous environment conditions as high temperatures, poisonous materials and inside unsafe buildings.



Figure 3: FFR-1 Fire Fighting and Rescue Wireless Robot (bowen39, 2012)

Operating FFR-1 enables firefighters to execute missions in confined spaces, narrow streets, industrial buildings, stores, tunnels, airports, military installations, power plants, chemical plants and others. FFR-1 is easily transported on a modified vehicle or a trailer, imparting an operational advantage for firefighters at early stage of the fire as well as during the whole operation. The FFR-1 has a internal double-walled cooling system to avoid the overheating cause by high external temperature. FFR-1 is a highly maneuverable robot with cross-country capabilities. It runs on treads and can climb up to 30 degree incline dragging a 3 inch fire hose (Mgsemi, 2005).

### ***FIREMOTE 4800:***

The Firemote 4800 illustrated in Figure 4 is an Unmanned Ground Vehicle. It is equipped with a fire-fighting nozzle, high pressure water equipment, spray nozzle, navigation cameras, thermal imaging camera, cooling system and roll-flat hose inlet. All the equipment is contained in a stainless steel insulated body which can reflect radiant heat. It can also protect tracks and sensitive parts by circulating water through chassis and using fixed nozzle to cool down the body. The Firemote 4800 is controlled from a panel by the help of color cameras consisted of 2 forward facing and 2 rearward facing, angled to give wide field of view. The panel uses a trans-reflective monitor that shows a software dashboard with the Firemote 4800's parameters and images from the 4 cameras simultaneously for ease of navigation. The command centre can receive video from the panel as it has an inbuilt computer that can record or send on video files.



Figure 4: Firemote 4800

(Photo reprinted from Ryland Research Limited Company, 2011)

### ***MVF-5:***

The MVF-5 as shown in Figure 5 is a multifunctional robotic fire fighting machine manufactured by Croatian manufacturer DOK-ING, to put out fires in unreachable areas and life threatening conditions. It is a fire fighting vehicle that operated by a single operator and controlled by using remote control. With the remote-control technology GPS-INS (Global Position System- Inertial Navigation System), the system is able to be controlled in the range of 1500m.



Figure 5: MVF-5 Autonomous Fire Fighting Machine

(Photo reprinted from DOK-ING Company, 2010)

The MVF-5 helps to assist the firefighters to secure high risk infrastructure. It also extinguishes fires without intervention of firefighters with high-pressure cannon on a hydraulic arm that pumps water up to 55 m away. The MVF-5 has a high-temperature-resistant fire protection shield. The protection shield is based on reflective in tumescent materials that bubble, expand in volume, and become denser when exposed to fire. DOK-ING Company claimed that the multilayer coatings on MVF-5 are able to withstand 700 C for 15 minutes or 400 C for 30 minutes, making it suitable for high-temperature areas. The MVF-5 can spray 2000 liters of water or foam per minute. The tank capacity is 2200 liters of water and 500 liters of foam. The high pressure cannon which is fitted on the specially



designed 3-level hydraulic arm has 360° rotation. This enables high pressure cannon delivering of the extinguishing liquids in all desired directions (DOK-ING Company, 2010).

#### ***JMX-LT50:***

JMX-LT50 (Figure 6) is equipped with barrier ability, the long-distance remote control, and the formidable spray water class. This robot is made up of the remote-controller, chassis, liquid-control fire monitor and control system. The robot is utilizing the water supplied from rear coupling and it is able to protect itself by automatic mist spraying. The remote control water cannon of the robot is able to spray the water in different angle and distance. The mobility of JMX-LT50 is using the wheel-tire moving structure. This design made this robot move in the different terrain and overcome different kind of obstacle (Chinawe, 2013).



Figure 6: JMX LT50 (Photo reprinted from Chinawe, 2013)

#### ***SACI 2.0:***

The Brazilian made water-blasting robot named SACI (Figure 7) was introduced in 2006. SACI is able to put off the fire by directing the water stream, foam blast or a fog blowing technique. The machine When extinguishing fire, this machine will produce a maximum blast of 60 meters, and the cannon pivots from 20 - 70 degrees vertically while being wheeled around on the tank-like track system. It can have water cannons capable to have a water flow up to 7,600 liters per minute. There are two Foam Generator Liquid reservoirs with 25 liters capacity each build internally (ARMTEC, 2013).



Figure 7: SACI 2.0 (Photo reprinted from ARMTEC, 2013)

This machine can pump fluids for three solid hours before needing a recharge. Other than that, it can operate with a full load capacity up to a minimum of six hours. For convenience, this machine has its charging system mounted in its transport car. It has lighting system to light up the dark environment when on duty. SACI firefighting robot was designed and built with modular approach. Besides, SACI is equipped with a trapezoidal track that is capable to cross different obstacles.

#### ***ArchiBot-M:***

The Korean designed firefighting robot, namely, ArchiBot-M (Figure 8) is the mobile robot that used in the human inaccessible location. It is used for on-site checking and clears the path for fire fighter. The robot was equipped with an special designed independent suspension system for stair climbing and working in high temperature. The robot also is designed with waterproof ability and equipped with a cooling system in order the robot to be worked in the hot environment.



Figure 8: ArchiBot-M (Photo reprinted from Drbfatec, 2013)

### *Thermite T2*

The Thermite robot (Figure 9) is developed to be handled different hazardous environment such as forest fire and chemical fires. The robot equipped with remote capabilities to ensure the robot is able to control with stand-off distance and a multi-directional monitor to ensure the safety of the user. The remote control distance is around 400 m. The Thermite is designed for rough terrain as well as building environment. The robot has short start up time that is enable the robot has shorter respond time.

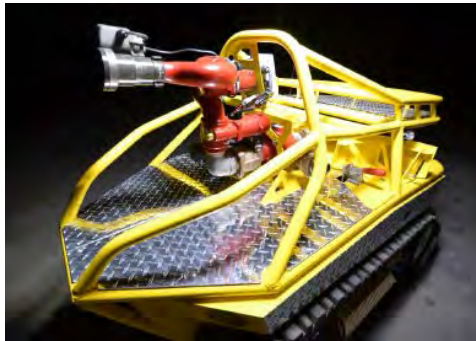


Figure 9: Thermite T2 (Photo reprinted from Howeandhowe, 2013)

### *FIGOV*

The developed of Fire Fighting Ground Vehicle (FIGOV) is a remotely controlled machine consists of a mobile and rigid chassis. The robot is designed and developed in Malaysia. The different view of FIGOV is showed in Figure 10 and Figure 11. The machine is wirelessly controlled via mobile computer. The nozzle of the machine can be directed at different angle and can be elevated in order to control fire at different height. One of the great importance of the development of the Fire Fighting Machine is it can reduce the risks faced by fire fighters in performing their duties. This is due to the fact to the current fire fighting techniques require fire fighters to intervene in hazardous conditions. Working at high temperature, dusty, low humidity, dangerous and others are among usual working conditions associated with fire fighting. The FIGOV system is a ground vehicle that was equipped with long-range control and monitoring ability for firefighting and rescue purpose. The FIGOV is capable of fire fighting and searching purpose in a hazardoud environment. In addition, the FIGOV is using green energy, which is electric, to power the machine. The current FIGOV will be equipped with state of the art sensor and imaging system to detect and locate fire victim. The first generation of FIGOV was developed in the year 2006. Currently, the 4<sup>th</sup> generation of FIGOV is under development process. The new design of the FIGOV will equipped with better track system, lighter structure, controllable multi-directional water cannon, long range wireless CCTV, common platform as well as long range control capability. The common based of FIGOV will be built as well in order the FIGOV can be used for different purposed. The technical specification of FIGOV is shown in Table 8.



Figure 10: Side View of FIGOV



Figure 11: FIGOV

Table 1: General specifications of the FIGOV

| <b>Specification</b> | <b>Description</b>           |
|----------------------|------------------------------|
| Weight               | 910 kg                       |
| Height               | 1300 mm                      |
| Length               | 1500 mm                      |
| Width                | 1000 mm                      |
| Body                 | Mild steel                   |
| Power Sources        | Battery                      |
| Speed                | 2.36 km/h                    |
| Water Cannon         | Single water nozzle          |
| Track System         | Heavy duty rubber track belt |
| Traction             | NA                           |

### **3.0 DESIGN ANALYSIS WATER SPRAYING SYSTEM**

The engineering design analysis is conducted on the structure of the FIGOV in order to ensure its reliability to withstand the load experienced during operation. As water is projected from a nozzle to form a 'jet' or fire fighting stream, the nozzle tends to recoil in the opposite direction. Therefore, it is essential to counter the hose nozzle reactive force generated during fire fighting process. Manual calculation and computer aided engineering software utilizing Finite element analysis is applied in the study. Analysis made consider the maximum load applied on the machine and the maximum water pressure experienced by the machine during operation. Calculation made is to check the stability of the machine when the machine is in use.

Computer Aided Engineering (CAE) and design optimization is becoming more crucial in modern engineering design. It is because it applies numerical techniques to engineering systems in order to assist the engineering designers. This approach will be useful in improving the system's performance, weight, reliability, and/or cost.

CAE analysis and optimization methodologies can be applied during the product development stage to ensure that the finished design will have the high performance, high reliability, low weight, and/or low cost. Alternatively, design optimization methods can also be applied to existing products to identify potential design improvements. After completing design analysis, the prototype fabrication of the FFM proceeded. The prototype produced is a full scale prototype.

#### **3.1 Pressure Loss Analysis**

##### ***Pressure Loss through Hose and Height***

During operation, Pressure loss is a term used to describe the decrease in pressure from one point in a tube or hose to another point downstream. Pressure drop is the result of frictional forces on the fluid as it flows through the hose. The frictional forces are caused by a resistance to flow. However, the increase of height at the exit of flow will also cause loss of pressure. Figure 4 shows the schematic of pressure loss factor. In determining the pressure loss, Bernoulli's equation is used.

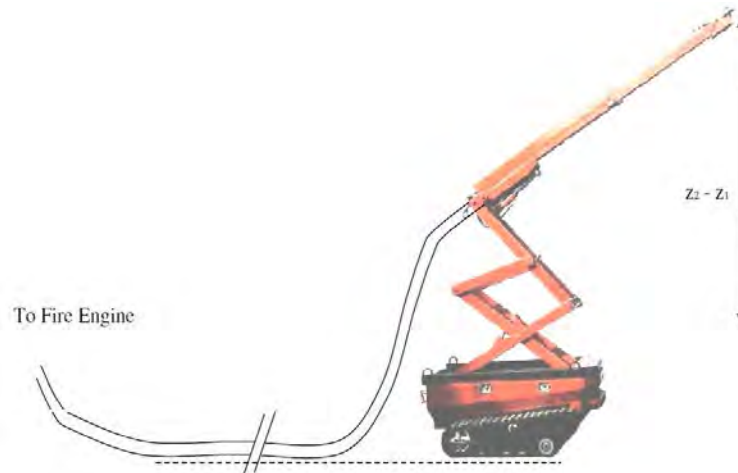


Figure 12: Pressure loss due to hose length and height

Bernoulli Principle which relates pressure, velocity and elevation between two points in flow field is applied. Assumption made using the principle is the flow is steady, incompressible, irrotational and nonviscous. The following formula is used in Fire and Rescue Department.

$$EP = NP + FL_{Hose} + FL_{Appliance} \pm P_{Elevation} \quad (1)$$

Where,

EP = Engine Pressure

NP = Nozzle Pressure

$FL_{Hose}$  = Friction Loss in the fire hose

$FL_{Appliance}$  = Friction Loss in the appliance

$P_{Elevation}$  = Pressure loss or gain due to elevation

Based on Manual of Firemanship Book 7: Hydraulics, pumps and pump operation, There is the friction loss occur in fire hose. The friction loss is a function of hose diameter, hose length, discharge volume any appliance used such as wyes or monitors used in the hose layout. The basic of calculation in fire hydraulic revolves around three fundamental hydraulic principles namely, Bernoulli's Equation, Darcy-Weibach Equation and Continuity Equation. Friction Loss Formula as given in Equation (4.1) is derived from these three basic equations.

Friction loss in the hose,  $FL_{Hose}$  is given by a Friction Loss Equation as below [18]

$$FL_{Hose} = CQ^2L \quad (2)$$

Where,

FL = friction loss (expressed in psi)

C = coefficient of friction

Q = flow rate in hundreds of gallons (gpm/100)

L = Length of hose in hundreds of feet (L/100)

Based on Bernoulli's equation, it is given that:

$$P_1 + \rho gz_1 + \frac{1}{2} \rho V_1^2 = P_2 + \rho gz_2 + \frac{1}{2} \rho V_2^2 + FL \quad (3)$$

Where,

$P$  = Pressure

$\rho$  = Fluid density

$g$  = Gravity

$z$  = Height

$V$  = Fluid velocity

$h_f$  = Friction losses

Whereas based on Continuity equation, it is known that:

$$Q = A_1V_1 = A_2V_2 \quad (4)$$

Where,

$Q$  = Volume flow rate

$A$  = Cross section area

$V$  = Fluid velocity

### Nozzle Force

In analyzing force at nozzle of FFM, the system can be considered as a thermodynamic system that has an open system or control volume and involves the flow of fluid through the fixed volume. As fluid moves through the control volume, the mass entering the control volume is equal to the mass leaving the control volume. The surface enclosing the control volume is referred to as the control surface. The force at nozzle is determined with information such as, maximum water pressure and nozzle dimension using Bernoulli's equation and momentum equation. The components involved in the force determination of the nozzle as shown in Figure 5.

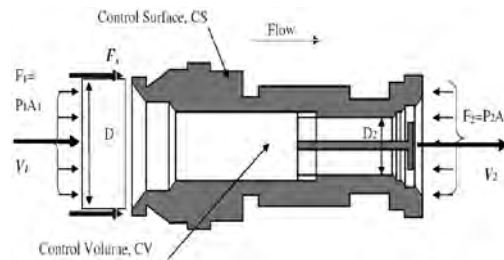


Figure 13: Cross sectional view of water nozzle

The water inlet and outlet velocity  $V_1$  and  $V_2$  can be obtained by solving Continuity Equation.

$$V_1 = \frac{Q}{A_1} = \frac{4Q}{\pi D_1^2} \quad (5)$$

Based on the Friction Loss, the Nozzle Pressure can be calculated based on the following formula. (Referring to NFPA 1002 Standard of Fire Apparatus Driver/Operator Professional Qualifications)

$$EP = NP + FL_{Hose} + FL_{Appliance} \pm P_{Elevation} \quad (6)$$



### 3.2 Results

#### *Pressure Loss through Hose and Height*

$$\text{Flow rate, } Q_2 = V_2 A_2 = 629.257 \text{ gpm}$$

Therefore, Friction Loss is

$$FL = 0.00065V_2^2 = 1.399 \text{ kPa}$$

Based on the Friction Loss, the Nozzle Pressure can be calculated based on the following formula.

$$NP = 11.64 \text{ bar}$$

#### *Nozzle Force*

For,  $D_1=0.0635m$ ,  $D_2 = 0.03302m$ ,  $Q = 0.0397m^3 s^{-1}$ , the water inlet and outlet velocity  $V_1$  and  $V_2$  obtained by solving Continuity Equation.

$$V_1 = \frac{Q}{A_1} = \frac{4Q}{\pi D_1^2} = 12.53ms^{-1}$$

$$V_2 = \frac{Q}{A_2} = \frac{4Q}{\pi D_2^2} = 46.36ms^{-1}$$

Based on the Friction Loss, the Nozzle Pressure can be calculated based on the following formula.

$$NP = EP - FL_{Hose} - FL_{Appliance} \pm P_{Elevation} = 11.64 \text{ bar}$$

Bernoulli's Momentum equation is used to determine the force,  $F_{nozzle}$ , required to hold the nozzle in its position.

$$F_{nozzle} = \rho Q(V_2 - V_1) - P_1 A_1 + P_2 A_2 = -2,257 N$$

Therefore the nozzle reaction force or minimum force required to hold the nozzle is 2.257 N.

#### 4.0 CONCEPTUAL DESIGN OF TRACK SYSTEM

Figure 14 is the first conceptual design of the fire fighting machine. This concept is to produce a light weight track system which needs a lower power to move it compared to the current fire fighting machine track system. It uses a timing belt type as its track. By using timing belt, it can operate over a very wide range of speeds. Besides that, no lubricant is needed. A timing belt also does not stretch appreciably or slip and consequently transmits power at a constant angular ratio. The design of the track at both ends is inclined shape. This enables the track to move easily on rocky terrain. It is also able to run smoothly as it can run over the large rock easily with such design comparing to the more flat type. For its chassis, it is only use a simple bar type where only a simple bar is holding the sprockets, suspensions and roller while it is connected to the fire fighting machine body. This can save a lot of material (cost) since it does not have complicated structure. Furthermore, it will become lighter when the structure of the track system is simplified. The suspension system used in this concept is the motorcycle type absorber. It is because it is easy to find in the market and it is easy to be installed.

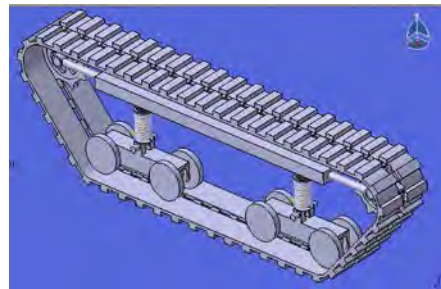


Figure 14: Conceptual design 1

Figure 15 shows the second conceptual design of the track system. For the track system, it is same as the first conceptual design which is using the timing belt as its track since it can operate in a wide range speed with no lubricant is needed and consequently transmit power at a constant angular-velocity ratio. It also has inclined shape at both ends so it can move smoothly on a rocky place especially if the fire fighting machine enter into a house where a lot of collapse bricks. For the chassis, it uses the moment resistance frame type. Moment resistance frame type is being chosen because it has few advantages. Firstly, it can resist bending moments and combination loading. Secondly, the frame can have large open space through the inside and this make the installation of other components become easier. Moreover, it can also save cost as it uses less material with simple structure. Thirdly, it is easy to be welded as the entire frame members are all joined and right angles. Lastly, failure of a single member does not necessarily result in catastrophic failure of the whole frame system, adjacent members can take some of the extra loading after one member has failed. The suspension used in this track system is torsion bar type. The main advantages of a torsion bar suspension are durability, easy adjustability of ride height, and small profile along the width of the vehicle.

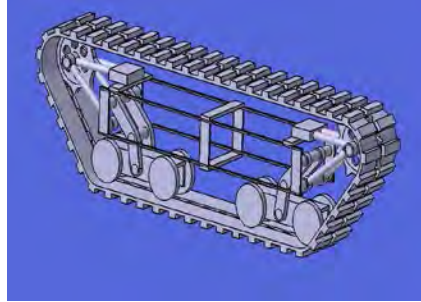


Figure 15: Conceptual design 2

The third conceptual design of track system in Figure 16 uses roller chain as its track. Roller chain is used because there is no slippage or creep is involved. Hence, there is no power lost due to slippage. Besides that, it has the ability to drive a number of shafts from a single source of power. Moreover, roller chain seldom failed because they lack of tensile strength. Chain drives are also more practical at slow speeds, yet will operate efficiently at high temperatures. Furthermore, chains are generally easier to install than belts. On the others hand, they are not subject to deterioration by oil, grease, or sunlight, and generally withstand chemical and abrasive conditions. Chains can also operate in wet conditions while stretch under normal operating conditions is slow, and chains require less take-up adjustment than do belts. Chains are suitable for use on reversing drives too. Some soft materials are attached to the roller chain in order to make it quiet when it is rolling on the ground. For the chassis, rigid frame type is used as it is suitable to withstand high moment, stress and force. It also can hold the components of the track system tightly. Besides that, it is also a good choice as it not easy spoiled due to the vibration and shock since it is rigid. For the suspension, it is same as first conceptual design where it uses motorcycle shock absorber.

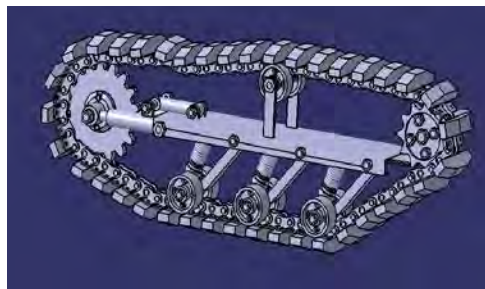


Figure 16: Conceptual design 3

#### 4.1 Concept Selection

There are many methods to evaluate the concept design. One of the methods used is the Weight Decision Matrix. It is a method of evaluating competing concepts by ranking the design criteria with weighting factors and scoring the degree to which each design concept meets the criterion. Table 2 shows the Weight Decision Matrix used to evaluate the new track system.

Table 2: Weight decision method

| DESIGN CRITERION   | WEIGHT FACTOR | UNITS      | CONCEPTUAL DESIGN 1 |         |        | CONCEPTUAL DESIGN 2 |         |        | CONCEPTUAL DESIGN 3 |         |        |
|--------------------|---------------|------------|---------------------|---------|--------|---------------------|---------|--------|---------------------|---------|--------|
|                    |               |            | MAGNITUDE           | SCORING | RATING | MAGNITUDE           | SCORING | RATING | MAGNITUDE           | SCORING | RATING |
| MATERIAL COST      | 0.12          | RM         | LOW                 | 8       | 0.96   | MEDIUM              | 7       | 0.84   | MEDIUM              | 7       | 0.84   |
| MANUFACTURING COST | 0.16          | RM         | LOW                 | 8       | 1.28   | MEDIUM              | 7       | 1.12   | HIGH                | 6       | 0.96   |
| REPAIRABILITY      | 0.12          | RM         | HIGH                | 8       | 0.96   | MEDIUM              | 7       | 0.84   | MEDIUM              | 7       | 0.84   |
| DURABILITY         | 0.18          | EXPERIENCE | LOW                 | 6       | 1.08   | MEDIUM              | 7       | 1.26   | HIGH                | 8       | 1.44   |
| TIME TO PRODUCE    | 0.12          | HOUR       | FAST                | 8       | 0.96   | MEDIUM              | 7       | 0.84   | MEDIUM              | 7       | 0.84   |
| RELIABILITY        | 0.18          | EXPERIENCE | LOW                 | 6       | 1.08   | MEDIUM              | 7       | 1.26   | HIGH                | 8       | 1.44   |
| EFFICIENCY         | 0.12          | PERCENTAGE | LOW                 | 6       | 0.72   | MEDIUM              | 7       | 0.84   | HIGH                | 8       | 0.96   |
| <b>TOTAL</b>       |               |            |                     |         | 7.04   |                     |         | 7.00   |                     |         | 7.32   |

There are three conceptual design evaluated in the Weight Decision Matrix. Firstly, the design criteria are identified by which the concepts will be evaluated. The design criteria are identified as (1) material cost, (2) manufacturing cost (3) reparability, (4) durability, (5) reliability, (6) time to produce and (7) efficiency. Next, each of the design criteria is given weighting factor. It is done in the objective tree. The weighting factor will be used in the Weight Decision Matrix in the Table 2. The score in the table 3 is derived according to 11-point scale.

The rating for each concept at each design criterion is obtained by multiplying the score by the weighting factor. Thus, for the criterion of material cost in the first conceptual design, the rating is  $0.12 \times 8 = 0.96$ . The overall rating for each concept is the sum of these ratings.

After total all the rating, the conceptual design 3 has the highest ranking followed by conceptual design 1 and lastly is the conceptual design 2. Their rating is 7.32, 7.04 and 7.00 respectively. Therefore, conceptual design 3 is selected as the new design for fire fighting machine.

#### 4.2 Optimization Using MSC ADAMS

MSC ADAMS is used for optimize the position of the roller holder and the suspension. By using the software which is illustrated in Figure 17, test and error is done to check the right position of the roller holder and the suspension. In the software, the roller holder was built using rigid link body. The suspension was built using the translational spring damper. Different lengths of the roller holder have been tried and the different inclined angles of the suspension also have been tested to find the better position. The length, angle and the position of them form the chassis will affect the efficiency of the track system. The parameter use for the optimization is shown in Table 2.4. The best position is chosen by comparing the acceleration of each position.

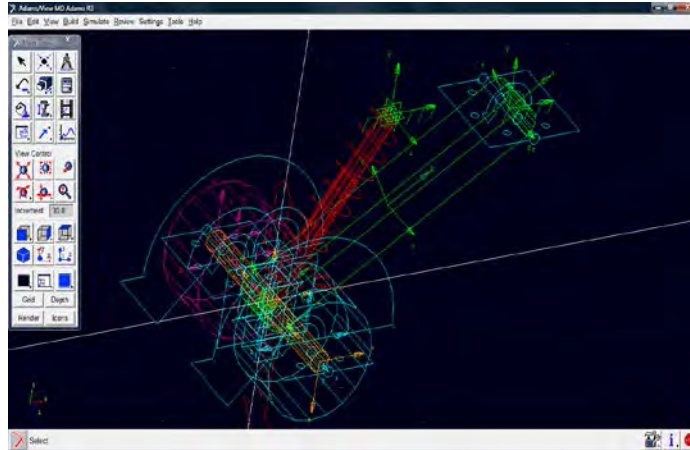


Figure 17: Optimization of the position of the roller holder and absorber in the track system using MSC ADAMS

Table 3: Parameter used in MSC ADAMS for optimization

| PARAMETERS           | UNIT          |
|----------------------|---------------|
| RUNNING TIME         | 100 s         |
| FORCE ON SPRING      | 300 N         |
| ROLLER INITIAL SPEED | -50.0d * time |

## 5.0 CONCLUSION

In this paper, the pressure loss of nozzle and nozzle force has been analyzed. Three fundamental hydraulic principles were used to analyze the nozzle, namely, Bernoulli's Equation, Darcy-Weibach Equation and Continuity Equation. Based on the calculation, total pressure loss of nozzle is 11.64 bar. For the nozzle force, the nozzle reaction force to hold the nozzle is 2257 N.

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2. **Tan, C.F.**, Ranjit. S.S.S. and Anas, S.A. 2012. Water Pressure Loss Analysis of Mobile Machine for Fire Fighting Purpose. **International Journal of Soft Computing and Engineering**, 1(6):437-440.