

# DP IB Maths: AI SL

## 4.6 Normal Distribution

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## 4.6.1 The Normal Distribution

### Properties of Normal Distribution

The binomial distribution is an example of a discrete probability distribution. The normal distribution is an example of a **continuous** probability distribution.

#### What is a continuous random variable?

- A continuous random variable (often abbreviated to CRV) is a random variable that can take **any value** within a range of infinite values
  - Continuous random variables **usually measure** something
  - For example, height, weight, time, etc

#### What is a continuous probability distribution?

- A continuous probability distribution is a probability distribution in which the random variable  $X$  is continuous
- The probability of  $X$  being a **particular value is always zero**
  - $P(X = k) = 0$  for any value  $k$
  - Instead we define the **probability density function**  $f(x)$  for a specific value
    - This is a function that describes the **relative likelihood** that the random variable would be close to that value
  - We talk about the **probability** of  $X$  being within a **certain range**
- A continuous probability distribution can be represented by a continuous graph (the values for  $X$  along the horizontal axis and probability **density** on the vertical axis)
- The **area under the graph** between the points  $X = a$  and  $X = b$  is equal to  $P(a \leq X \leq b)$ 
  - The **total area under the graph equals 1**
- As  $P(X = k) = 0$  for any value  $k$ , it does not matter if we use strict or weak inequalities
  - $P(X \leq k) = P(X < k)$  for any value  $k$  when  $X$  is a **continuous random variable**

#### What is a normal distribution?

- A normal distribution is a **continuous probability distribution**
- The **continuous random variable**  $X$  can follow a normal distribution if:
  - The distribution is **symmetrical**
  - The distribution is **bell-shaped**
- If  $X$  follows a normal distribution then it is denoted  $X \sim N(\mu, \sigma^2)$ 
  - $\mu$  is the **mean**
  - $\sigma^2$  is the **variance**
  - $\sigma$  is the **standard deviation**
- If the **mean** changes then the graph is **translated horizontally**

- If the **variance** increases then the graph is **widened horizontally** and **made shorter vertically** to maintain the same area
  - A **small variance** leads to a **tall** curve with a **narrow** centre
  - A **large variance** leads to a **short** curve with a **wide** centre

### What are the important properties of a normal distribution?

- The **mean** is  $\mu$
- The **variance** is  $\sigma^2$ 
  - If you need the **standard deviation** remember to square root this
- The normal distribution is symmetrical about  $X = \mu$ 
  - Mean = Median = Mode =  $\mu$
- There are the results:
  - Approximately **two-thirds (68%)** of the data lies within **one standard deviation** of the mean ( $\mu \pm \sigma$ )
  - Approximately **95%** of the data lies within **two standard deviations** of the mean ( $\mu \pm 2\sigma$ )
  - Nearly **all of the data (99.7%)** lies within **three standard deviations** of the mean ( $\mu \pm 3\sigma$ )

## Modelling with Normal Distribution

### What can be modelled using a normal distribution?

- A lot of real-life continuous variables can be modelled by a normal distribution provided that the population is large enough and that the variable is **symmetrical** with **one mode**
- For a normal distribution  $X$  can take any real value, however values far from the mean (more than 4 standard deviations away from the mean) have a probability density of **practically zero**
  - This fact allows us to model variables that are not defined for all real values such as height and weight

### What can not be modelled using a normal distribution?

- Variables which have **more than one mode** or **no mode**
  - For example: the number given by a random number generator
- Variables which are **not symmetrical**
  - For example: how long a human lives for

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### Worked example

The random variable  $S$  represents the speeds (mph) of a certain species of cheetahs when they run. The variable is modelled using  $N(40, 100)$ .

- a) Write down the mean and standard deviation of the running speeds of cheetahs.

$$\mu = 40 \text{ and } \sigma^2 = 100$$

↑  
Square root to get standard deviation

Mean  $\mu = 40$   
Standard deviation  $\sigma = 10$

- b) State two assumptions that have been made in order to use this model.

We assume that the distribution of the speeds is

- symmetrical
- bell-shaped

## 4.6.2 Calculations with Normal Distribution

### Calculating Normal Probabilities

Throughout this section we will use the random variable  $X \sim N(\mu, \sigma^2)$ . For  $X$  distributed normally,  $X$  can take any real number. Therefore any values mentioned in this section will be assumed to be real numbers.

#### How do I find probabilities using a normal distribution?

- The **area under a normal curve** between the points  $x = a$  and  $x = b$  is equal to the **probability**  $P(a < X < b)$ 
  - Remember for a normal distribution you do not need to worry about whether the inequality is strict ( $<$  or  $>$ ) or weak ( $\leq$  or  $\geq$ )
    - $P(a < X < b) = P(a \leq X \leq b)$
- You will be **expected to use** distribution functions on your **GDC** to find the probabilities when working with a normal distribution

#### How do I calculate $P(X = x)$ : the probability of a single value for a normal distribution?

- The probability of a **single value** is **always zero** for a normal distribution
  - You can picture this as the area of a single line is zero
- $P(X = x) = 0$
- Your GDC is likely to have a "**Normal Probability Density**" function
  - This is sometimes shortened to NPD, Normal PD or Normal Pdf
  - **IGNORE THIS FUNCTION** for this course!
  - This calculates the **probability density function** at a point **NOT** the probability

#### How do I calculate $P(a < X < b)$ : the probability of a range of values for a normal distribution?

- You need a **GDC** that can calculate **cumulative normal probabilities**
- You want to use the "**Normal Cumulative Distribution**" function
  - This is sometimes shortened to NCD, Normal CD or Normal Cdf
- You will need to enter:
  - The 'lower bound' - this is the value  $a$
  - The 'upper bound' - this is the value  $b$
  - The ' $\mu$ ' value - this is the mean
  - The ' $\sigma$ ' value - this is the standard deviation
- **Check the order carefully** as some calculators ask for standard deviation before mean
  - Remember it is the standard deviation
    - so if you have the **variance** then **square root it**
- **Always sketch** a quick diagram to visualise which area you are looking for

#### How do I calculate $P(X > a)$ or $P(X < b)$ for a normal distribution?

- You will still use the "**Normal Cumulative Distribution**" function
- $P(X > a)$  can be estimated using an **upper bound that is sufficiently bigger** than the **mean**
  - Using a value that is more than 4 standard deviations **bigger than the mean** is quite accurate
  - Or an easier option is just to input lots of 9's for the upper bound (**99999999...** or  **$10^{99}$** )
- $P(X < b)$  can be estimated using a **lower bound that is sufficiently smaller** than the **mean**
  - Using a value that is more than 4 standard deviations **smaller than the mean** is quite accurate
  - Or an easier option is just to input lots of 9's for the lower bound with a negative sign (**-99999999...** or  **$-10^{99}$** )

### Are there any useful identities?

- $P(X < \mu) = P(X > \mu) = 0.5$
- As  $P(X = a) = 0$  you can use:
  - $P(X < a) + P(X > a) = 1$
  - $P(X > a) = 1 - P(X < a)$
  - $P(a < X < b) = P(X < b) - P(X < a)$
- These are useful when:
  - The mean and/or standard deviation are unknown
  - You only have a diagram
  - You are working with the **inverse distribution**

### Worked example

The random variable  $Y \sim N(20, 5^2)$ . Calculate:

i)  $P(Y = 20)$ .

Identify  $\mu$  and  $\sigma$   
 $\mu = 20$   $\sigma^2 = 5^2$  so  $\sigma = 5$

Sketch!



$$P(Y = 20) = 0$$

ii)  $P(18 \leq Y < 27)$ .

Sketch!



Using GDC  
 Lower = 18  
 Upper = 27

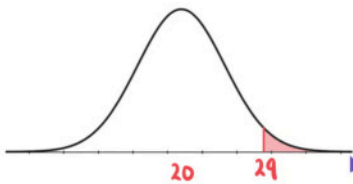
We can use  $\leq$  or  $<$

$$P(18 < Y < 27) = 0.574665...$$

$$0.575 \text{ (3sf)}$$

iii)  $P(Y > 29)$

Sketch!



Using GDC  
 Lower = 29  
 Upper = 99999

$$P(Y > 29) = 0.035930...$$

$$0.0359 \text{ (3sf)}$$

No upper bound so  
 choose a big number



## Inverse Normal Distribution

**Given the value of  $P(X < a)$  how do I find the value of  $a$ ?**

- Your **GDC** will have a function called "**Inverse Normal Distribution**"
  - Some calculators call this InvN
- Given that  $P(X < a) = p$  you will need to enter:
  - The 'area' - this is the value  $p$ 
    - Some calculators might ask for the 'tail' - this is the left tail as you know the area to the left of  $a$
  - The ' $\mu$ ' value - this is the mean
  - The ' $\sigma$ ' value - this is the standard deviation

**Given the value of  $P(X > a)$  how do I find the value of  $a$ ?**

- If your calculator **does** have the **tail option** (left, right or centre) then you can use the "Inverse Normal Distribution" function straightaway by:
  - Selecting 'right' for the tail
  - Entering the area as ' $p$ '
- If your calculator **does not** have the **tail option** (left, right or centre) then:
  - Given  $P(X > a) = p$
  - Use  $P(X < a) = 1 - P(X > a)$  to rewrite this as
    - $P(X < a) = 1 - p$
  - Then use the **method for  $P(X < a)$**  to find  $a$

### Worked example

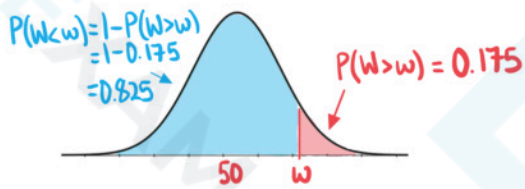
The random variable  $W \sim N(50, 36)$ .

Find the value of  $w$  such that  $P(W > w) = 0.175$ .

Identify  $\mu$  and  $\sigma$

$$\mu = 50 \quad \sigma^2 = 36 \quad \text{so } \sigma = 6$$

Sketch!



$P(W > w)$  is less than 0.5  
so  $w$  is bigger than the mean

Area from left is 0.825

Use Inverse Normal Distribution function on GDC

$$w = 55.6075...$$

$$w = 55.6 \text{ (3sf)}$$